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STABILITY AND CONTROL CHARACTERISTICS FROM MACH NUMBER 1.50 TO 2.86 OF A MODEL OF A MANNED LIFTING ENTRY VEHICLE [U]

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Langley Research Center

Langley Station, Hampton, Va.

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SUMMARY

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An investigation was conducted in the Langley Unitary Plan wind tunnel of a basic version of a manned lifting entry vehicle, designated HL-10, to determine the stability and control characteristics. The results of this investigation indicate that the configuration was longitudinally stable and self-trimming with good elevon effectiveness. Wide operational ranges of angles of attack and Mach number were available to this configuration wherein the lift-drag ratios were only slightly reduced from maximum. It was also shown that with the present fins the configuration was directionally unstable at the lower Mach numbers and higher angles of attack. The elevons provided high roll control effectiveness, and the center-fin-located rudder was adequate for directional control at all but the highest angles of attack and Mach numbers.

Conf.

Author

INTRODUCTION

As part of the general research effort at Langley Research Center on manned lifting entry vehicles having maximum hypersonic lift-drag ratios of about 1.0, an investigation has been undertaken to determine the aerodynamic characteristics and problems associated with this class of vehicle. After an extensive review of configurations and analysis of hypersonic and low-subsonic results on some selected preliminary configuration (refs. 1 to 3), one vehicle shape was selected for further study. The vehicle has been designated the basic HL-10 (horizontal lander 10). The results reported in reference 4 indicate that low directional stability is a problem area of the basic HL-10 at low supersonic speeds. The present investigation was made in the Langley Unitary Plan wind tunnel from Mach number 1.50 to 2.86 to provide supplemental information on directional stability and to extend the stability and control results of reference 4 to the lower supersonic Mach number range.

SYMBOLS

The results are presented as force and moment coefficients with lift, drag, and pitching moment referred to the stability axis system and rolling moment, yawing moment, and side force referred to the body axis system. The reference center of moments is located at 53-percent body length aft of the nose, and 1.25-percent body length below the body reference line. Zero angle on all control surfaces is defined as that condition where the surface is in line with the normal contours of elements of the model immediately upstream of the surface. The symbols used are defined as follows:

b	body reference span, 10.31 in.
l	body reference length, 16.00 in.
L	lift
D	drag
L/D	lift-drag ratio
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_{L_α}	lift-curve slope at $\alpha = 0^\circ$
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSl}$
C_{m_α}	slope of pitching-moment curve
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
C_{l_β}	effective dihedral parameter, $\frac{\Delta C_l}{\Delta\beta}$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
C_{n_β}	directional stability parameter, $\frac{\Delta C_n}{\Delta\beta}$
C_Y	side-force coefficient, $\frac{\text{Side force}}{qS}$

C_{Y_β} lateral-force parameter, $\frac{\Delta C_Y}{\Delta \beta}$

M free-stream Mach number

q free-stream dynamic pressure, lb/sq ft

r radius, in.

S reference planform area, 0.634 sq ft

X,Y,Z body axes

x,y,z ordinates along body axes

α angle of attack referred to body reference line, deg

α_{nom} nominal angle of attack (to nearest degree)

β angle of sideslip referred to plane of symmetry, deg

δ_e resultant angle of elevon, positive when trailing edge is down, $\frac{\delta_{e_{right}} + \delta_{e_{left}}}{2}$

δ_a resultant angle of aileron, positive deflection generates negative rolling moment, $\delta_{e_{right}} - \delta_{e_{left}}$

δ_r angle of rudder deflection, positive when trailing edge is deflected to left when viewed from rear, measured relative to surface of center fin

Subscripts:

max maximum

trim value at trim condition

Model component designations:

D-1 basic tip fin

$D\text{-}1_{mod}$ modified basic tip fin

E basic center fin

TEST CONDITIONS

The test conditions are summarized in the following table:

Mach number	Stagnation temperature, °F	Stagnation pressure, lb/sq ft abs	Reynolds number per ft
1.50	125	885	1.59×10^6
1.80	125	969	1.59
2.16	125	1133	1.59
2.86	125	1624	1.59

The stagnation dewpoint was maintained at -30° F in order to avoid condensation effects in the test section. Angles of attack and sideslip were corrected for deflection of the balance and sting support under load. The data here have been corrected for tunnel-flow angularity. The drag data presented are those measured during the investigation. No adjustment has been made to relate drag levels to a condition corresponding to free-stream static-pressure conditions at the model base.

Aerodynamic forces and moments were measured by means of a six-component electrical strain-gage balance housed within the model. The balance, in turn, was rigidly fastened to a sting support and thence to the tunnel support system. The angle-of-attack range of the tests extended from about 0° to 36° at angles of sideslip of about 0° and 5°. Data at angles of attack above 32° at $M = 1.50$ are possibly affected by reflected shock waves. This problem is not evident at the higher test Mach numbers.

The accuracy of the measured quantities, based on calibration and repeatability of data, is estimated to be within the following limits:

C_L	±0.002
C_D	±0.001
C_m	±0.002
C_l	±0.002
C_n	±0.001
C_Y	±0.001
α, deg	±0.10
β, deg	±0.10
M	±0.015

MODEL AND APPARATUS

Details of the model are presented in figures 1 and 2, and ordinates defining the profile cross-section shape of the model in table I. The model has a leading-edge sweep angle of 74°. The cross section has a rounded top with a partial flat width bottom and blunted leading edges. Directional stability is provided by two tip fins orientated at approximately 30° away from the vertical and a center fin located on the body upper surface in the plane of symmetry. The basic tip fin (fig. 1) is designated D-1 and is the same as tip fin D-1 of reference 3. The ratio of tip fin area, above the reference line projected to the plane of symmetry, to configuration planview area is 0.0595. A modification to the tip fin was made and is shown in figure 2. The modification consisted of small changes in the leading- and trailing-edge sweep angles as well as in fin span. The center vertical fin designated E is the same as center fin E of reference 3 and has a ratio of side area to model planview area of 0.0739.

Longitudinal and lateral trim and control are derived from two deflectable elevons located on the upper and lower surfaces of the basic body at the trailing edge (fig. 1). A wedge surface was provided on one side of the center fin (fig. 1) for directional control. The ratios of the planform area of the pitch controls and the side area of the yaw control to model planview area are 0.1099 and 0.0126, respectively.

Tests were conducted in the low Mach number test section of the Langley Unitary Plan wind tunnel which is a variable-pressure, continuous-flow tunnel (ref. 5). The test section is 4 feet square and 7 feet long. The nozzle leading to the test section is of the asymmetric, sliding-block type which permits a continuous variation in test-section Mach number from about 1.5 to 2.9.

PRESENTATION OF RESULTS

The results of the investigation are presented in the following figures:

Schlieren photographs at $M = 2.96$ presented in figure 3 were obtained from reference 4.

RESULTS AND DISCUSSION

Longitudinal Characteristics

The effect of modification of the tip fin on the longitudinal characteristics (fig. 4) is negligible. Because of the roll-out orientation of the tip fins, however, the stability of the body is increased considerably by addition (fig. 4) of the tip fins. The longitudinal control characteristics are shown in figure 5. These results indicate that for the limited range of control deflection angles tested (-15° to 15°), the controls provide trim capability over a wide range of angles of attack, 5° to 22° at $M = 1.50$ and 17° to 40° at $M = 2.86$. Although control effectiveness is reduced considerably by an increase in Mach number, the reduction in static stability also occurring with increase in Mach number results in this wide angle-of-attack trim capability.

The longitudinal characteristics at trim angles of attack of the basic model consisting of the body with tip fin D-1 and center fin E are summarized in figure 6 and compared with the results of reference 4 at the higher supersonic Mach numbers. The longitudinal characteristics with a -15° control deflection were obtained by interpolation of data in reference 4. The results show that at a Mach number of 1.50, the stability at trim is comparatively high and decreases substantially within the range of the present investigation ($M = 1.50$ to 2.86). In addition, because the trim angles of attack are greater at the higher Mach numbers, the values of trim C_L are also greater even though C_{L_α} is lower. Although the trim angle-of-attack range for deflected controls is large (5° to 48°), the results of this investigation and of reference 4 indicate less than a 15-percent change in maximum trimmed lift-drag ratio throughout the range of Mach numbers from 1.50 to 4.63.

Lateral Characteristics

The effects of the center fin and the modified tip fins on the lateral stability characteristics are shown in figure 7. The results show that the fins of the basic configuration contribute large stabilizing moments at low angles of attack but an increase in angle of attack has an unfavorable effect on their contribution to directional stability. The reduced contribution at high angles of attack results in the basic configuration being directionally unstable at angles of attack greater than 19° at a Mach number of 1.50 but approaches neutral stability as the Mach number increases. At the highest Mach number investigated ($M = 2.86$), the configuration is neutrally stable at intermediate angles of attack and stable at both low and high angles of attack. The configuration with modified tip fins has, for the most part, identical directional stability characteristics as the basic configuration.

The results (fig. 7) also show that the basic configuration has positive effective dihedral $\left(-C_{l_\beta}\right)$ throughout the Mach number and angle-of-attack range of the investigation and that the modification of the tip fin had little effect on the effective dihedral characteristics of the model.

The effectiveness of differential deflection of the elevons at $\delta_e = 0^\circ$ produced significant rolling moments with no adverse yawing moment (fig. 8). Comparison of these results with those of figures 9 and 10 illustrates the effect of combined deflection of the elevons and ailerons. The results show some effect of elevon deflection on the aileron effectiveness with variation in angle of attack and Mach number. Roll control is available throughout these ranges of attitude and speed.

The effectiveness of rudder deflection is shown in figure 11. The results indicate that the rudder effectiveness is adequate to provide directional control at all but the highest angles of attack and Mach numbers. In addition, considerable adverse roll is produced by deflection of the rudder which may be corrected by use of the ailerons.

CONCLUSIONS

An investigation has been made in the Langley Unitary Plan wind tunnel of the stability and control characteristics of a basic version of a manned lifting entry vehicle, designated HL-10, at Mach numbers from 1.50 to 2.86. The results of this investigation indicate the following conclusions:

1. The configuration was longitudinally stable and self-trimming throughout the test Mach number range with good control effectiveness for both positive and negative elevon deflections.

2. The maximum trimmed lift-drag ratio was not reduced appreciably within the test Mach number range.

3. This basic configuration was directionally unstable at the lower test Mach numbers at high angles of attack but has neutral or positive stability at the highest test Mach number (2.86).

4. The effectiveness of the differential elevons as roll control devices was good and produced no unfavorable yawing-moment characteristics. The rudder on the center fin was adequate to produce directional control at all but the highest angles of attack and Mach numbers.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., March 1, 1965.

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TABLE I.- CROSS-SECTION ORDINATES FOR HL-10 WITH TIP FINS OFF

x/l = 0.042

z/l	y/l
0.0541	0
.0532	.0083
.0503	.0167
.0441	.0250
.0375	.0306
.0333	.0338
.0250	.0390
.0167	.0431
.0083	.0459
0	.0476
-.0536	0

x/l = 0.083

z/l	y/l
0.0681	0
.0668	.0083
.0637	.0167
.0579	.0250
.0502	.0333
.0417	.0392
.0330	.0444
.0250	.0487
.0167	.0521
.0083	.0547
0	.0568
-.0083	.0585
-.0167	.0596
-.0752	0

x/l = 0.125

z/l	y/l
0.0737	0
.0729	.0083
.0702	.0167
.0660	.0250
.0594	.0330
.0505	.0417
.0417	.0477
.0333	.0528
.0250	.0571
.0167	.0604
.0083	.0632
0	.0656
-.0083	.0675
-.0167	.0691
-.0250	.0704
-.0333	.0714
-.0904	0

x/l = 0.167

z/l	y/l
0.0771	0
.0763	.0083
.0744	.0167
.0712	.0250
.0664	.0333
.0597	.0417
.0512	.0500
.0417	.0565
.0333	.0618
.0250	.0664
.0167	.0701
.0083	.0732
0	.0757
-.0083	.0778
-.0167	.0796
-.0250	.0811
-.0333	.0823
-.0417	.0833
-.0500	.0840
-.1026	0

x/l = 0.208

z/l	y/l
0.0792	0
.0787	.0083
.0772	.0167
.0747	.0250
.0712	.0333
.0664	.0416
.0592	.0500
.0517	.0583
.0417	.0656
.0333	.0713
.0250	.0760
.0167	.0800
.0083	.0833
0	.0860
-.0083	.0882
-.0167	.0902
-.0250	.0919
-.0333	.0933
-.0417	.0946
-.0500	.0955
-.0583	.0962
-.1126	0

x/l = 0.250

z/l	y/l
0.0807	0
.0803	.0083
.0792	.0167
.0773	.0250
.0748	.0333
.0712	.0417
.0666	.0500
.0606	.0583
.0527	.0667
.0458	.0721
.0417	.0754
.0333	.0811
.0250	.0862
.0167	.0902
.0083	.0937
0	.0965
-.0083	.0990
-.0167	.1011
-.0250	.1027
-.0333	.1044
-.0417	.1057
-.0500	.1067
-.0583	.1076
-.0667	.1083
-.1205	0

x/l = 0.292

z/l	y/l
0.0817	0
.0814	.0083
.0807	.0167
.0794	.0250
.0774	.0333
.0750	.0417
.0715	.0500
.0672	.0583
.0617	.0667
.0546	.0750
.0500	.0789
.0417	.0858
.0333	.0918
.0250	.0969
.0167	.1010
.0083	.1044
0	.1072
-.0083	.1098
-0.0167	0.1119
-.0250	.1137
-.0333	.1156
-.0417	.1170
-.0500	.1182
-.0583	.1192
-.0667	.1198
-.0750	.1202
-.1268	0

x/l = 0.333

z/l	y/l
0.0820	0
.0818	.0083
.0813	.0167
.0803	.0250
.0789	.0333
.0771	.0417
.0747	.0500
.0716	.0583
.0677	.0667
.0627	.0750
.0564	.0833
.0485	.0917
.0417	.0968
.0333	.1027
.0250	.1078
.0167	.1119
.0083	.1152
0	.1179
-.0083	.1204
-.0167	.1227
-.0250	.1250
-.0333	.1267
-.0417	.1282
-.0500	.1296
-.0583	.1306
-.0667	.1317
-.0750	.1321
-.1312	0

x/l = 0.375

z/l	y/l
0.0821	0
.0820	.0083
.0816	.0167
.0809	.0250
.0799	.0333
.0783	.0417
.0766	.0500
.0744	.0583
.0714	.0667
.0679	.0750
.0633	.0833
.0576	.0917
.0503	.1000
.0415	.1083
.0333	.1136
.0250	.1187
.0167	.1229
.0083	.1262
0	.1292
-.0083	.1315
-.0167	.1337
-.0250	.1358
-.0333	.1377
-.0417	.1394
-.0500	.1408
-.0583	.1420
-.0667	.1429
-.0750	.1437
-.0833	.1442
-.1334	0

x/l = 0.417

z/l	y/l
0.0814	0
.0813	.0083
.0811	.0167
.0805	.0250
.0797	.0333
.0786	.0417
.0772	.0500
.0755	.0583
.0733	.0667
.0706	.0750
.0674	.0833
.0633	.0917
.0582	.1000
.0517	.1083
.0437	.1167
.0375	.1211
.0333	.1241
.0250	.1296
.0167	.1339
.0083	.1375
0	.1406
-.0083	.1431
-.0167	.1453
-.0250	.1472
-.0333	.1492
-.0417	.1508
-.0500	.1523
-.0583	.1536
-.0667	.1546
-.0750	.1554
-.0833	.1559
-.1340	0

x/l = 0.458

z/l	y/l
0.0800	0
.0799	.0083
.0797	.0167
.0794	.0250
.0788	.0333
.0780	.0417
.0768	.0500
.0755	.0583
.0739	.0667
.0720	.0750
.0694	.0833
.0664	.0917
.0629	.1000
.0581	.1083
.0526	.1167
.0453	.1250
.0363	.1333
.0292	.1379
.0250	.1407
.0167	.1454
.0083	.1491
0	.1521
-.0083	.1549
-.0167	.1571
-.0250	.1592
-.0333	.1611
-.0417	.1627
-.0500	.1642
-.0583	.1654
-.0667	.1664
-.0750	.1672
-.0833	.1677
-.1322	0

x/l = 0.500

z/l	y/l
0.0782	0
.0782	.0167
.0780	.0250
.0776	.0333
.0770	.0417
.0762	.0500
.0751	.0583
.0738	.0667
.0723	.0750
.0705	.0833
.0682	.0917
.0655	.1000
.0620	.1083
.0579	.1167
.0529	.1250
.0467	.1333
.0390	.1417
.0333	.1458
.0250	.1521
.0167	.1571
.0083	.1612
0	.1643
-.0083	.1672
-.0167	.1694
-.0250	.1715
-.0333	.1733
-.0417	.1750
-.0500	.1763
-.0583	.1775
-.0667	.1785
-.0750	.1792
-.1285	0

x/l = 0.542

z/l	y/l
0.0759	0
.0759	.0166
.0758	.0249
.0756	.0332
.0752	.0415
.0747	.0498
.0740	.0581
.0730	.0664
.0718	.0747
.0705	.0830
.0688	.0913
.0666	.0996
.0642	.1079
.0611	.1162
.0575	.1245
.0530	.1328
.0476	.1411
.0410	.1494
.0326	.1577
.0249	.1629
.0166	.1685
.0083	.1729
0	.1764
-.0083	.1790
-.0166	.1815
-.0249	.1834
-.0332	.1853
-.0415	.1869
-.0498	.1882
-.0581	.1893
-.0664	.1902
-.1229	0

x/l = 0.583

z/l	y/l
0.0741	0
.0741	.0104
.0740	.0271
.0735	.0437
.0726	.0604
.0710	.0771
.0671	.0937
.0668	.1020
.0651	.1104
.0626	.1187
.0596	.1270
.0563	.1354
.0521	.1437
.0471	.1520
.0412	.1604
.0337	.1687
.0250	.1756
.0167	.1813
.0083	.1860
0	.1897
-.0083	.1926
-.0167	.1949
-.0250	.1970
-.0333	.1988
-.0417	.2003
-.0500	.2017
-.0583	.2028
-.1156	0

x/l = 0.625

z/l	y/l
0.0716	0
.0716	.0104
.0716	.0271
.0713	.0437
.0707	.0604
.0696	.0771
.0678	.0937
.0655	.1104
.0637	.1187
.0616	.1270
.0591	.1354
.0558	.1437
.0521	.1520
.0478	.1604
.0429	.1687
.0365	.1770
.0292	.1842
.0250	.1878
.0167	.1941
.0083	.1991
0	.2028
-.0083	.2057
-.0167	.2080
-.0250	.2101
-.0333	.2118
-.0417	.2132
-.0500	.2143
-.1073	0

x/l = 0.667

z/l	y/l
0.0687	0
.0686	.0208
.0686	.0375
.0684	.0541
.0678	.0708
.0669	.0875
.0655	.1041
.0634	.1208
.0601	.1374
.0580	.1458
0.0553	0.1541
.0522	.1624
.0483	.1708
.0439	.1791
.0385	.1874
.0317	.1958
.0250	.2015
.0167	.2080
.0083	.2128
0	.2167
-.0083	.2197
-.0167	.2218
-.0250	.2237
-.0333	.2254
-.0417	.2264
-.0986	0

x/l = 0.708

z/l	y/l
0.0654	0
.0653	.0417
.0651	.0583
.0650	.0750
.0643	.0916
.0634	.1083
.0617	.1250
.0596	.1416
.0582	.1499
.0563	.1583
.0542	.1666
.0517	.1749
.0487	.1833
.0446	.1916
.0398	.1999
.0340	.2083
.0292	.2130
.0250	.2168
.0167	.2235
.0083	.2283
0	.2317
-.0083	.2343
-.0167	.2363
-.0250	.2378
-.0333	.2390
-.0889	0

x/l = 0.750

z/l	y/l
0.0617	0
.0616	.0625
.0615	.0791
.0611	.0958
.0606	.1125
.0596	.1291
.0581	.1458
.0561	.1624
.0533	.1791
.0488	.1958
.0458	.2041
.0421	.2124
.0372	.2207
.0333	.2256
.0292	.2307
.0250	.2347
.0167	.2409
.0083	.2447
0	.2470
-.0083	.2491
-.0167	.2504
-.0250	.2511
-.0785	0

x/l = 0.792

z/l	y/l
0.0578	0
.0577	.0937
.0576	.1104
.0573	.1270
.0569	.1437
.0561	.1604
.0549	.1770
.0532	.1937
.0506	.2103
.0486	.2187
.0460	.2270
.0425	.2353
.0375	.2437
.0333	.2481
.0250	.2551
.0167	.2588
.0083	.2611
0	.2624
-.0083	.2631
-.0167	.2634
-.0673	0

x/l = 0.833

z/l	y/l
0.0536	0
.0534	.1666
.0532	.1833
.0528	.1999
.0521	.2166
.0510	.2332
.0482	.2499
.0455	.2582
.0400	.2666
.0333	.2707
.0250	.2736
.0167	.2749
.0083	.2753
0	.2753
-.0563	0

x/l = 0.875

z/l	y/l
0.0487	0
-.0452	0

x/l = 0.917

z/l	y/l
0.0440	0
-.0341	0

x/l = 0.958

z/l	y/l
0.0392	0
-.0227	0

x/l = 1.000

z/l	y/l
0.0344	0
-.0125	0

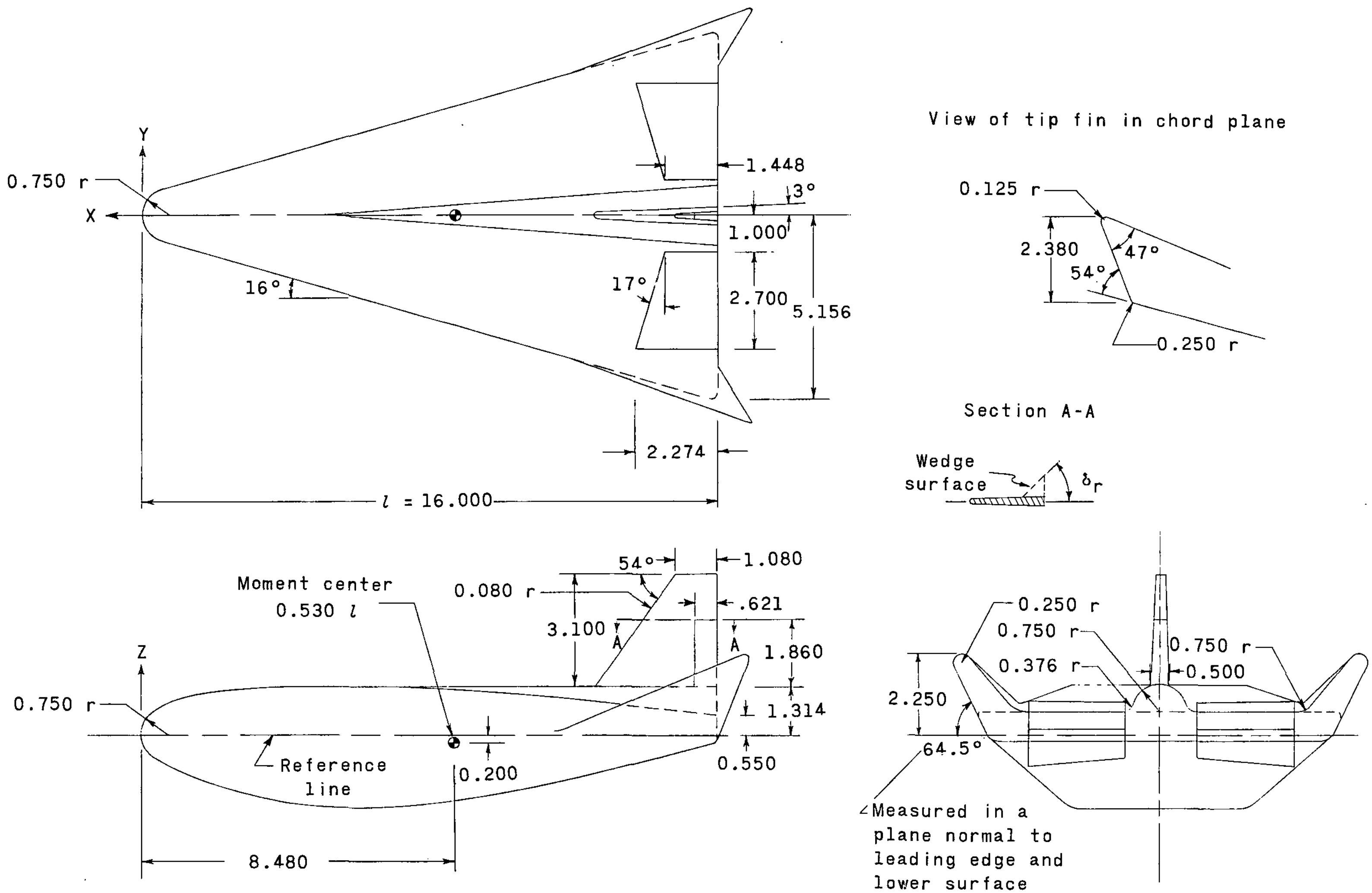
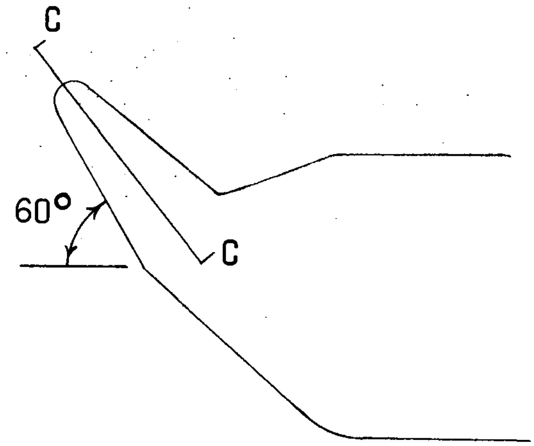
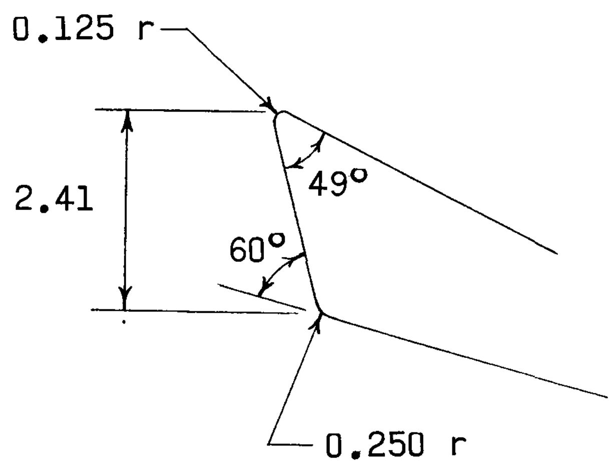


Figure 1.- Drawing of test model. All dimensions are in inches unless otherwise specified.



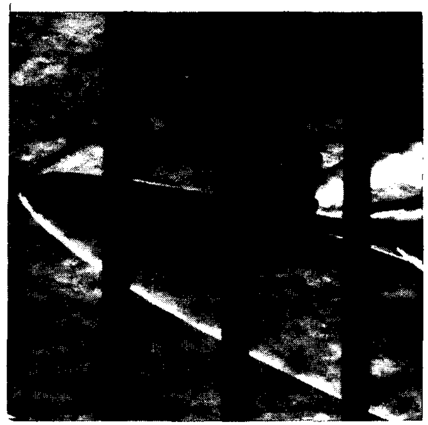
Rear View



Section C-C
(Rotated to chordplane)

Figure 2.- Drawing of modified tip fin D-1. All dimensions are in inches unless otherwise specified.

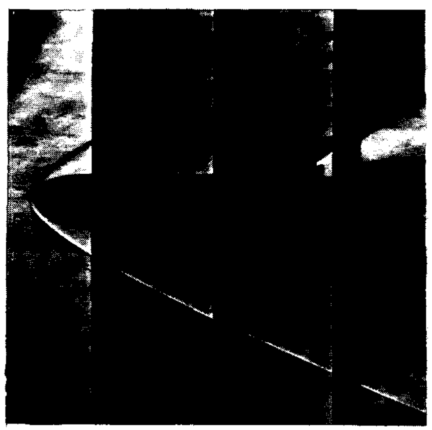
$\alpha_{nom} = 0°$



$\alpha_{nom} = 8°$

$\alpha_{nom} = 24°$

$M = 2.86;\ \delta_e = \delta_a = \delta_r = 0°$



$\alpha_{nom} = 0°$

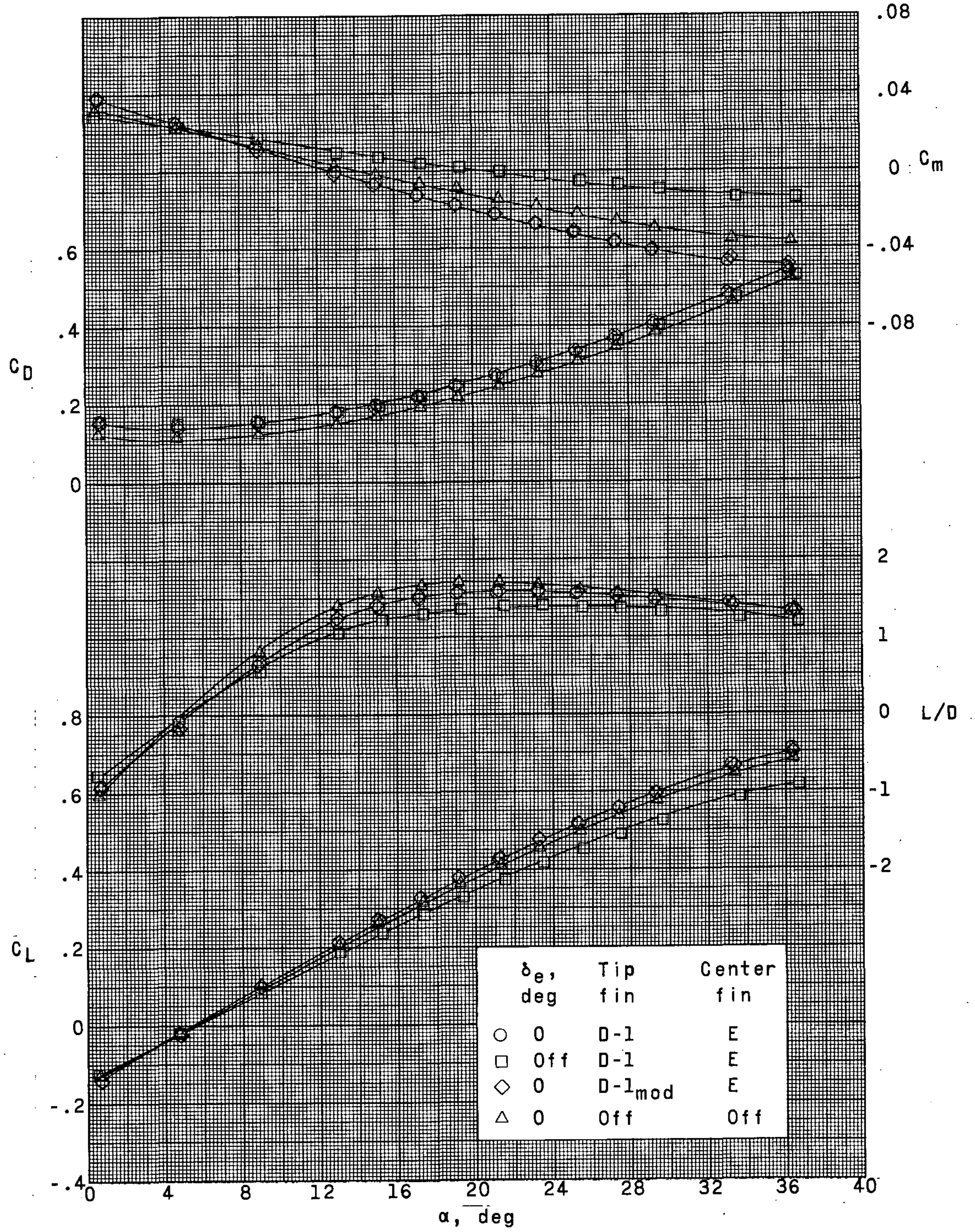
$\alpha_{nom} = 20°$

$\alpha_{nom} = 40°$

$M = 2.96;\ \delta_e = -30°,\ \delta_a = \delta_r = 0°$

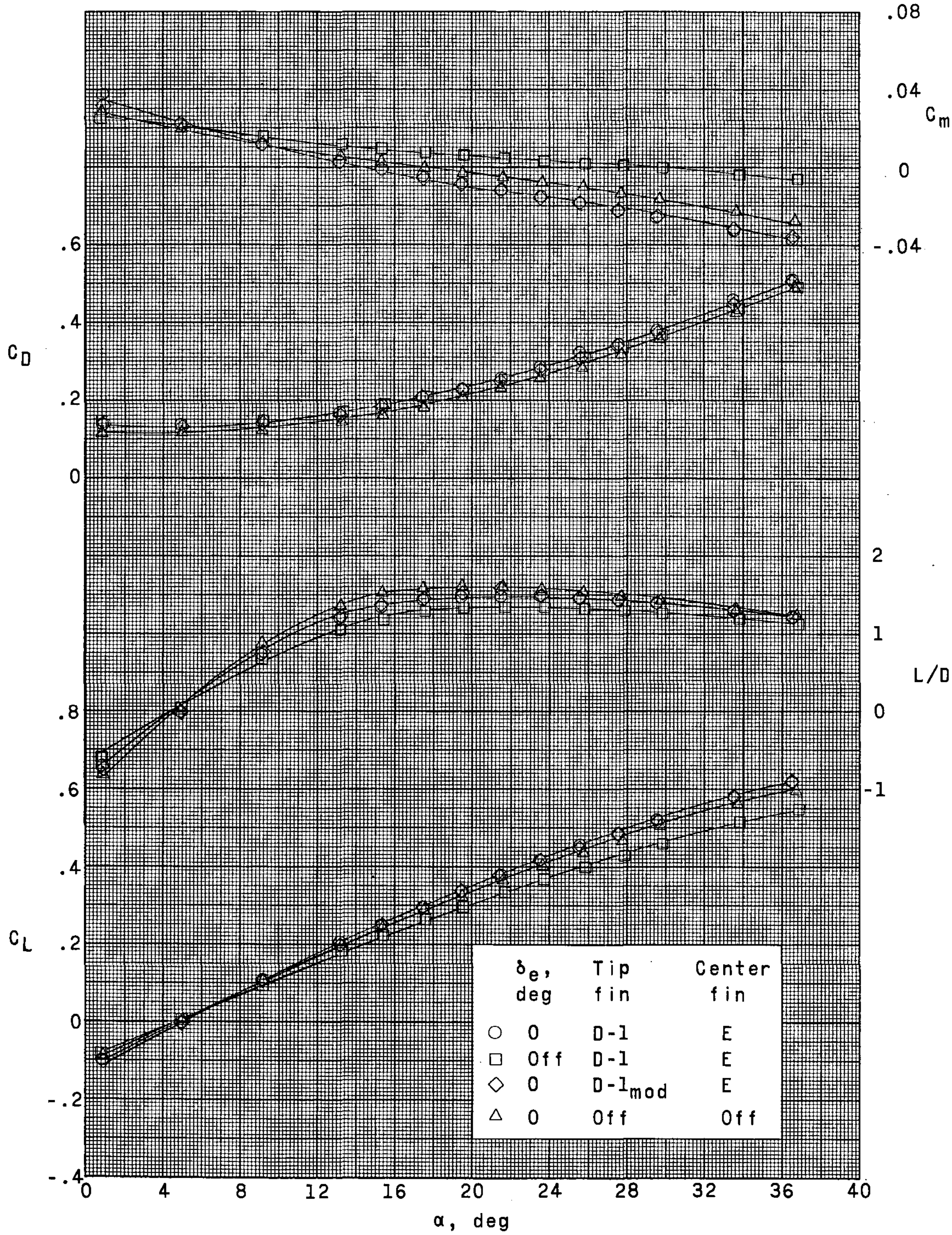
Figure 3.- Typical schlieren photographs of model.

L-65-35



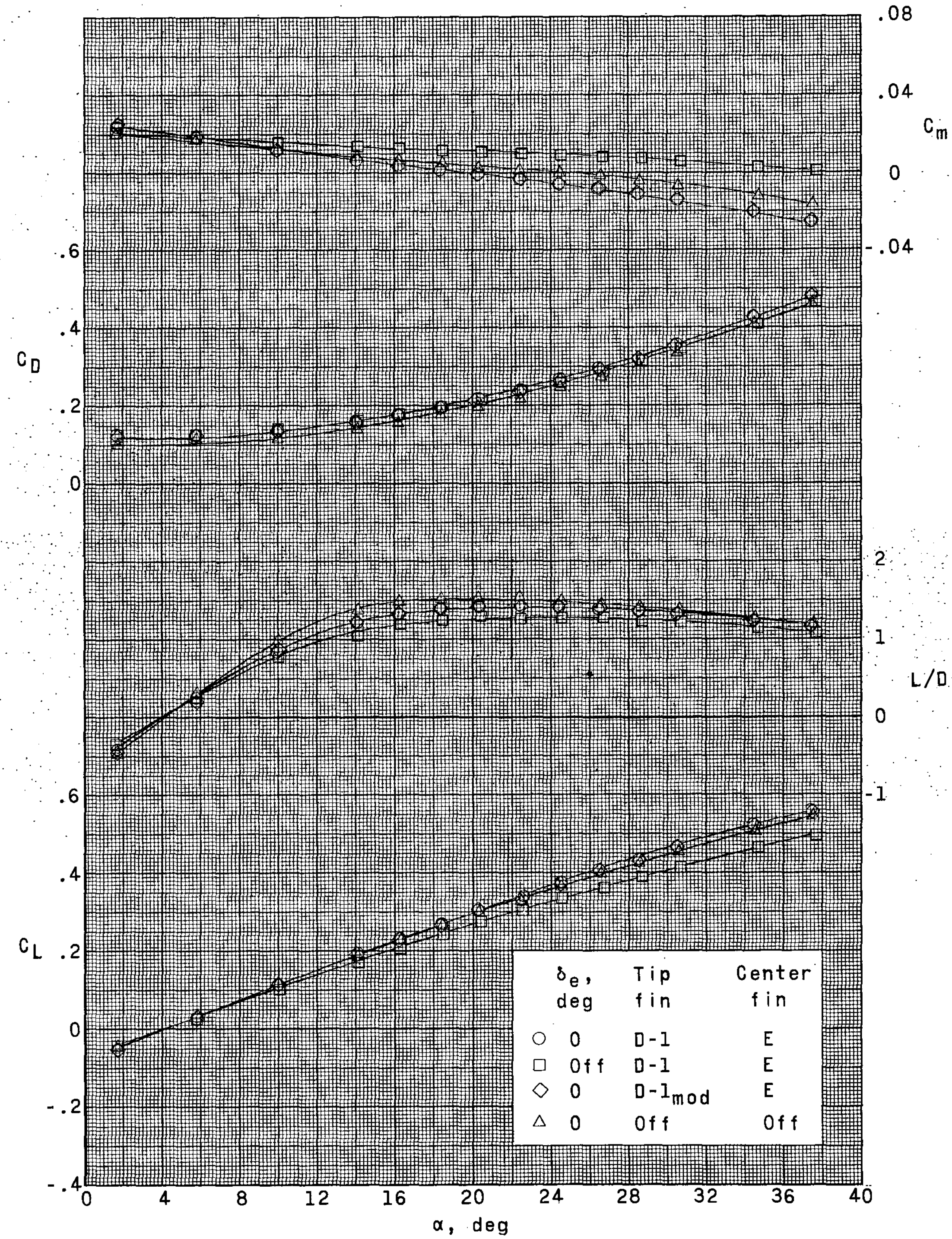
(a) M = 1.50.

Figure 4.- Variation of longitudinal characteristics of various model configurations with angle of attack. $\delta_r = 0^{\circ}$.



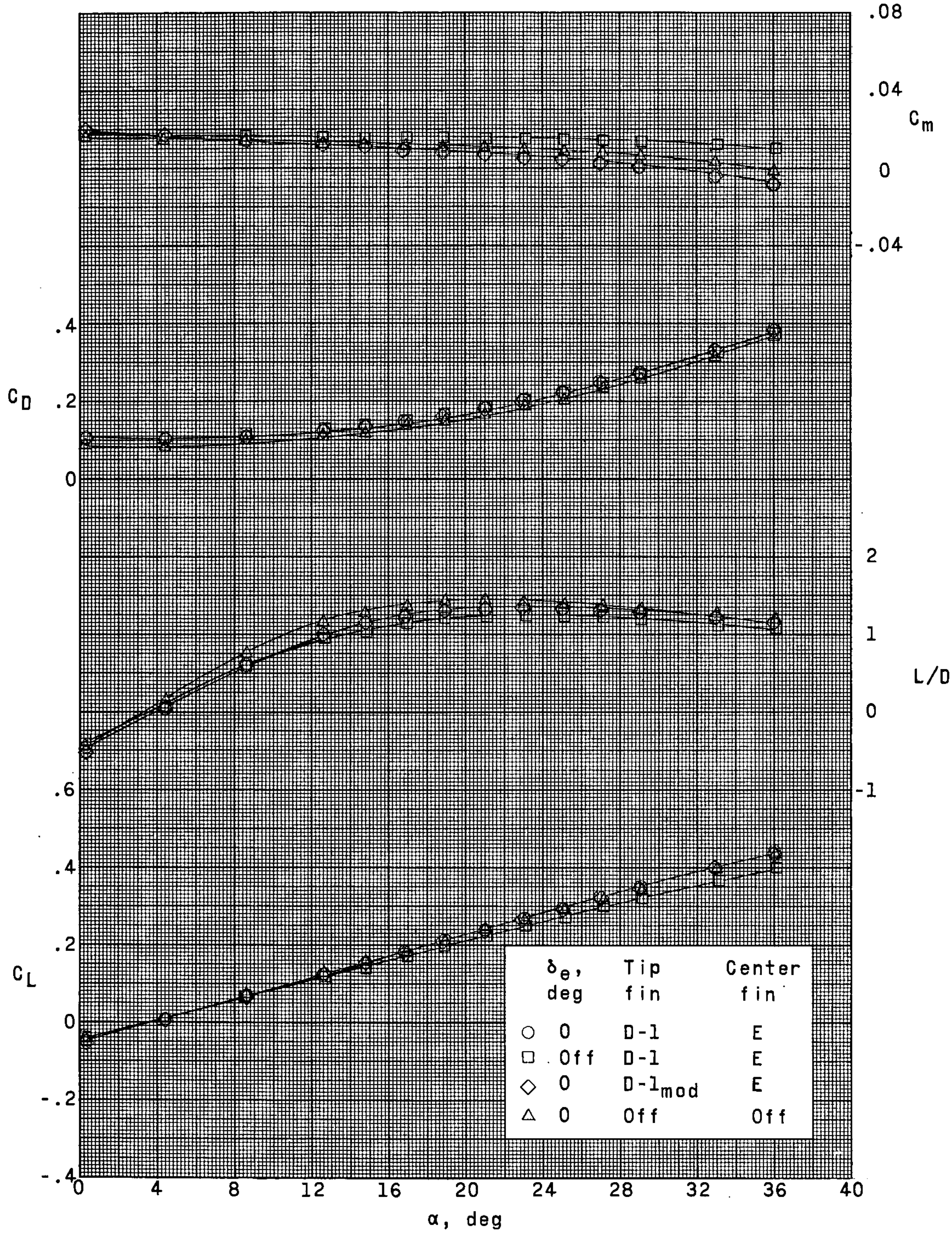
(b) M = 1.80.

Figure 4.- Continued.



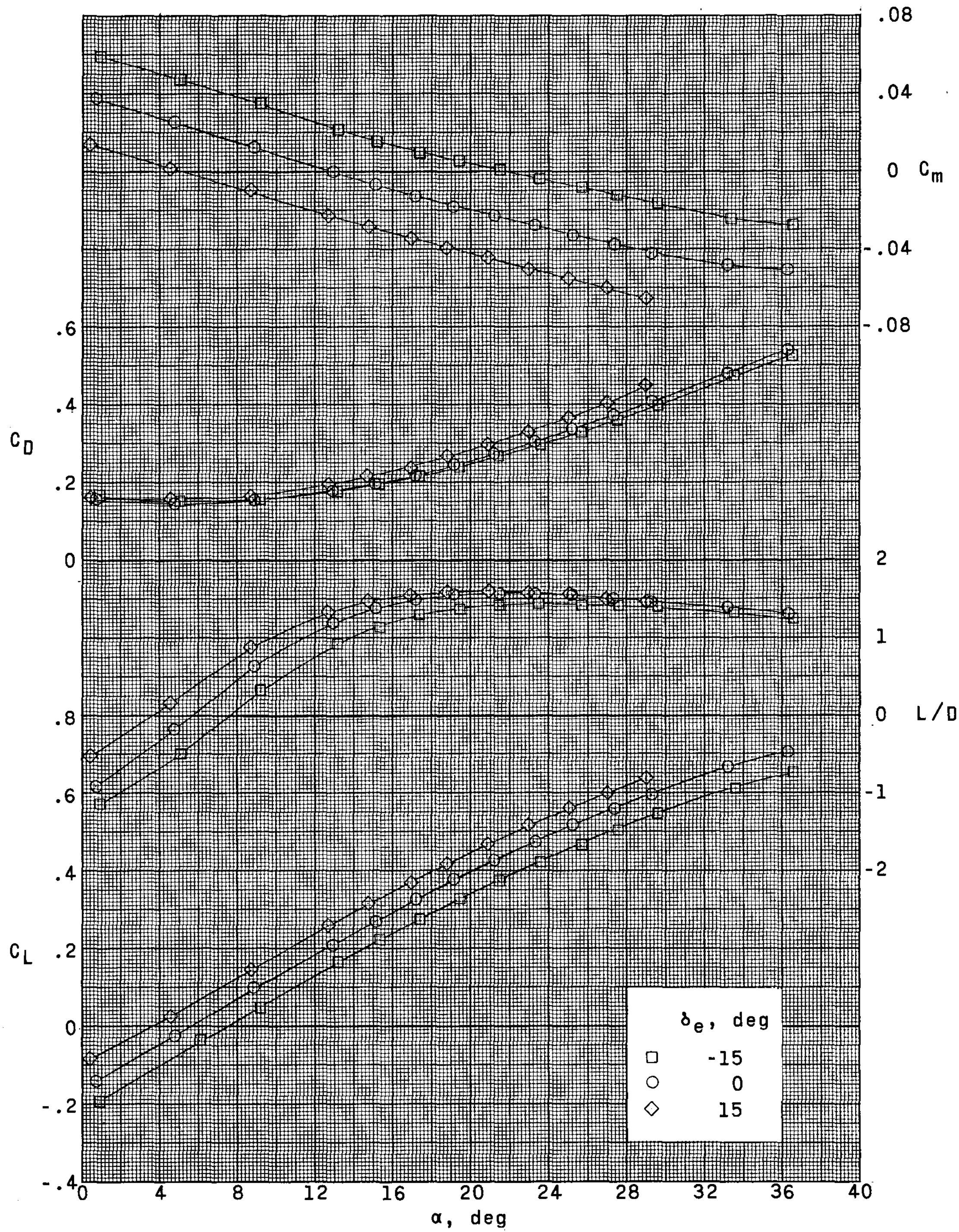
(c) M = 2.16.

Figure 4.- Continued.



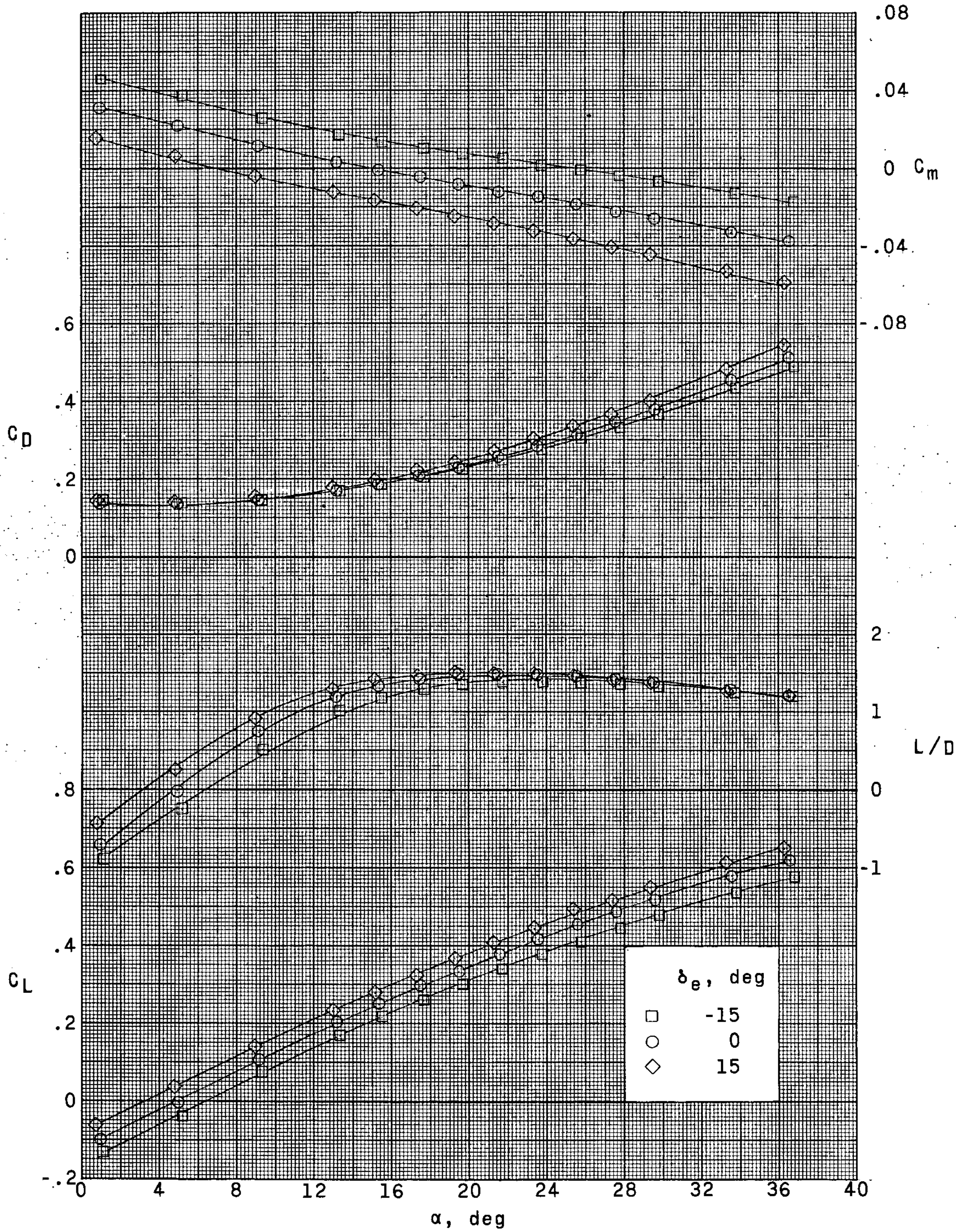
(d) M = 2.86.

Figure 4.- Concluded.



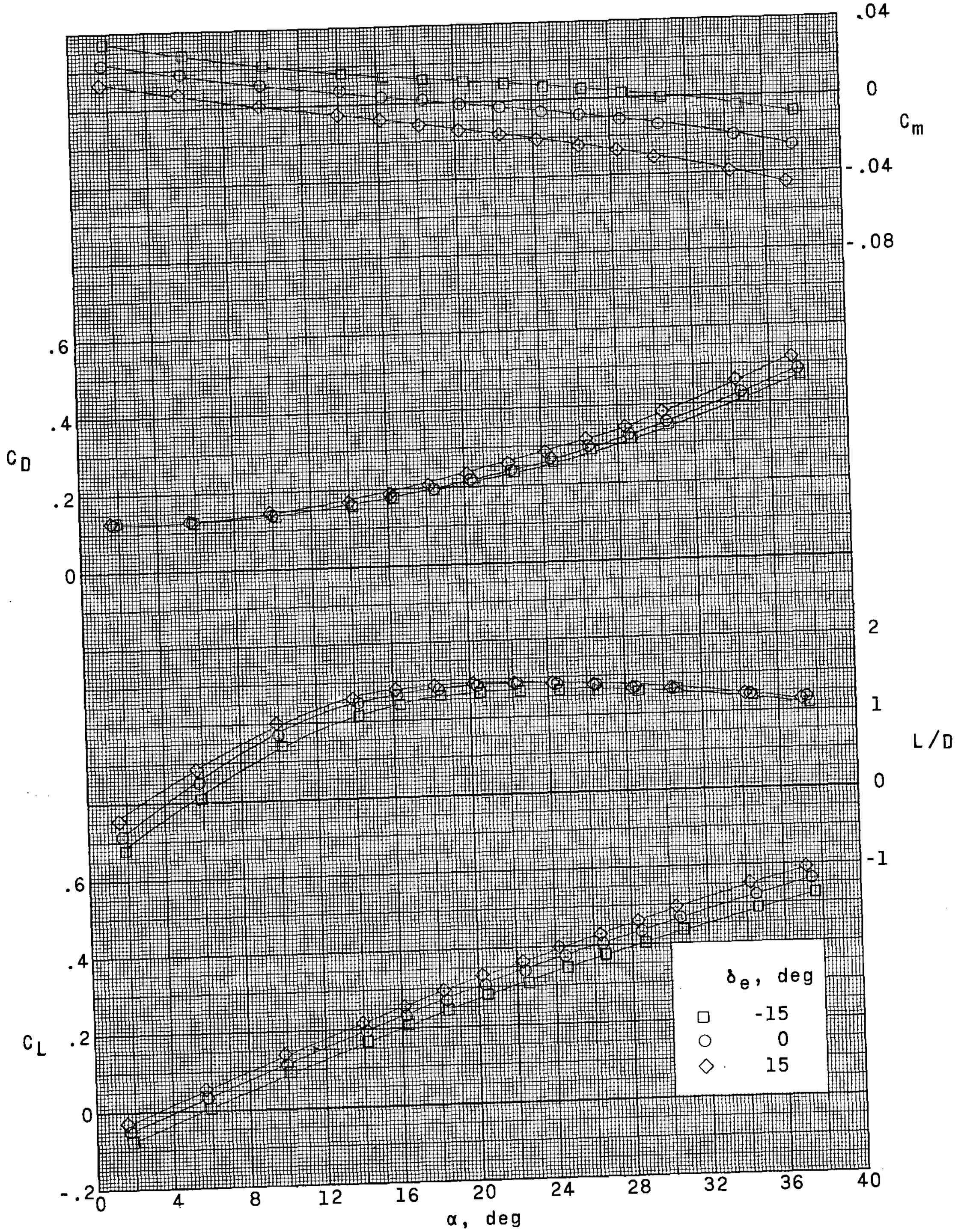
(a) M = 1.50.

Figure 5.- Variation of longitudinal characteristics of basic model with angle of attack for various pitch control deflections. $\delta_a = \delta_r = 0^{\circ}$.



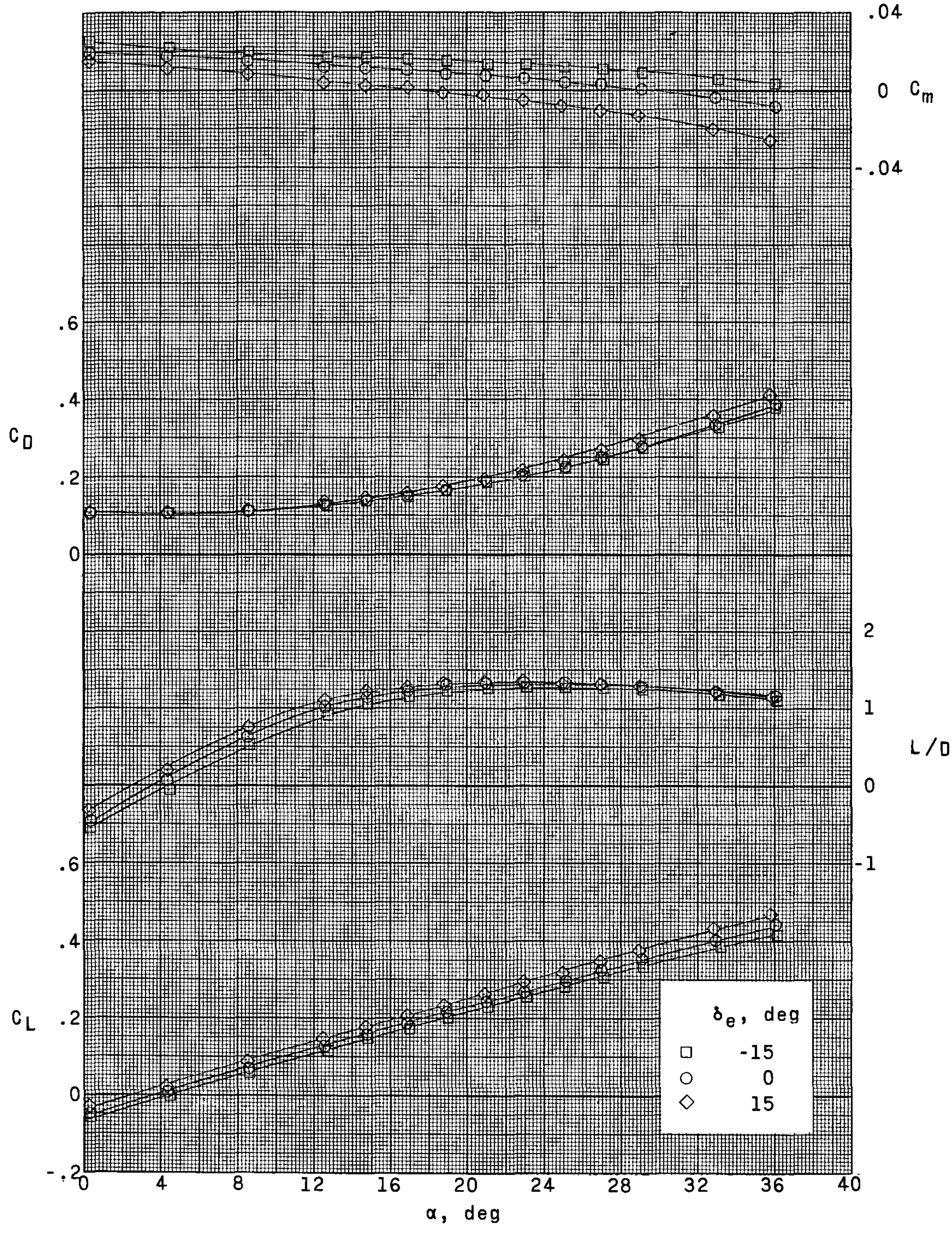
(b) M = 1.80.

Figure 5.- Continued.



(c) M = 2.16.

Figure 5.- Continued.



(d) M = 2.86.

Figure 5.- Concluded.

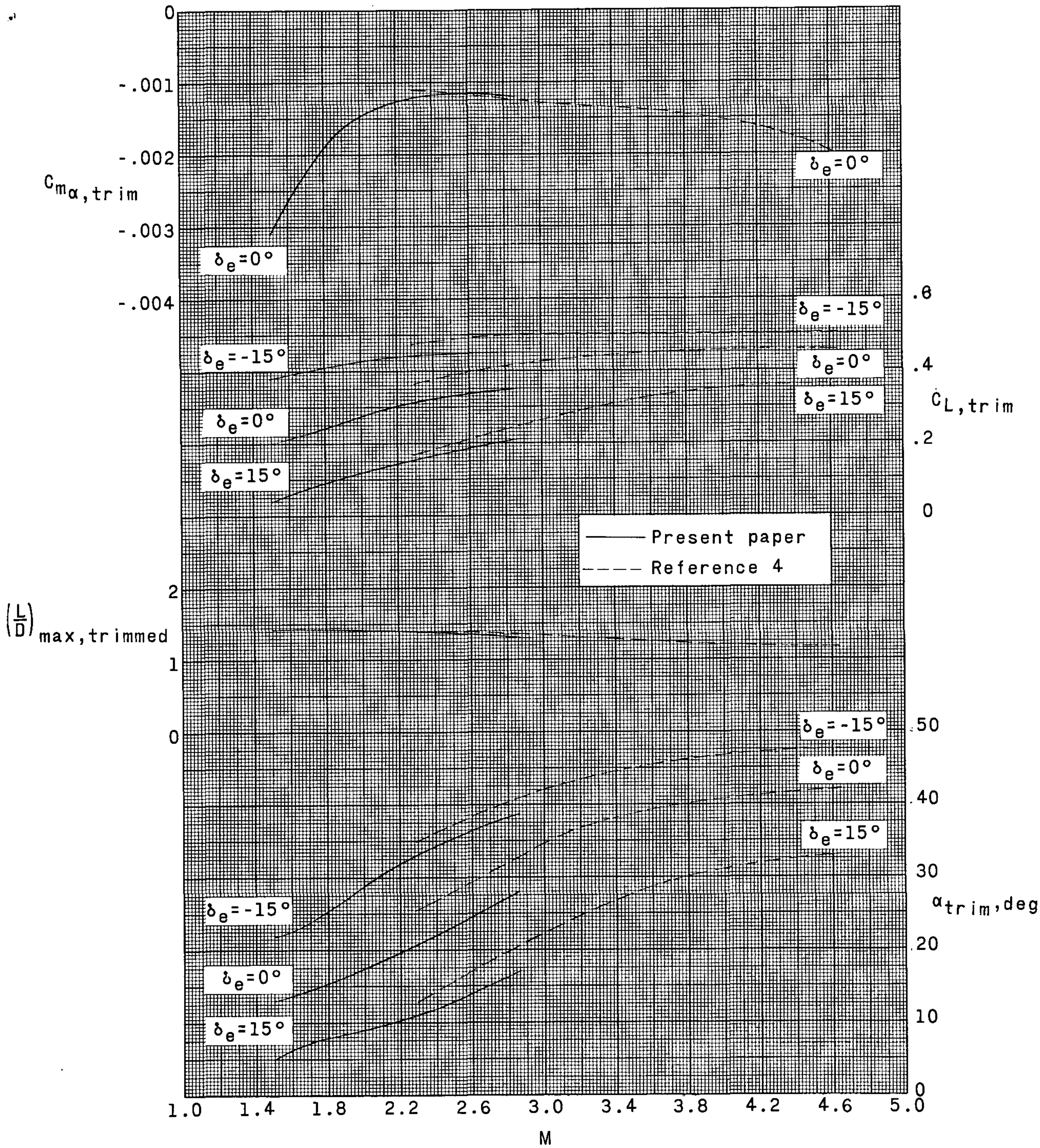
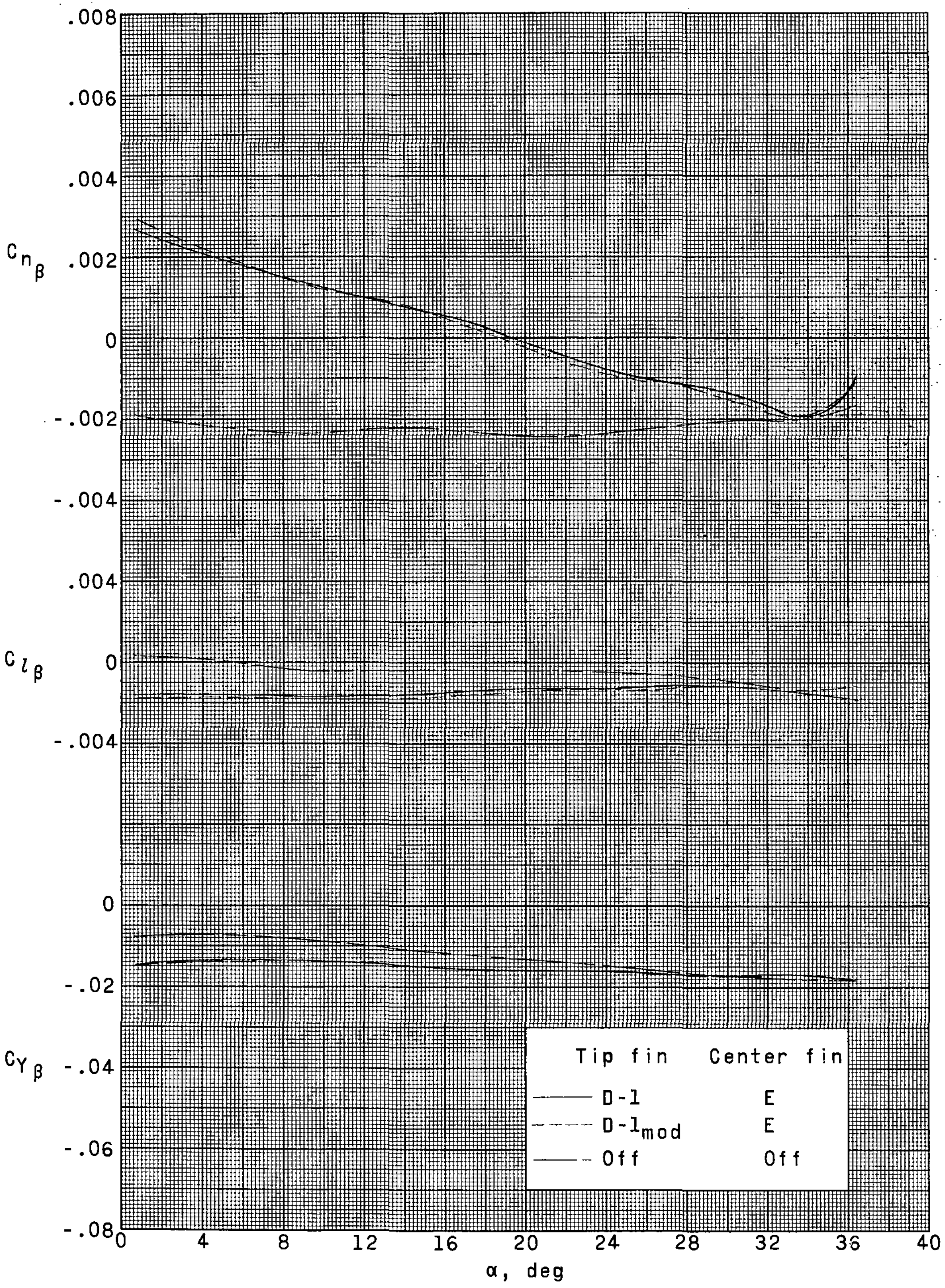
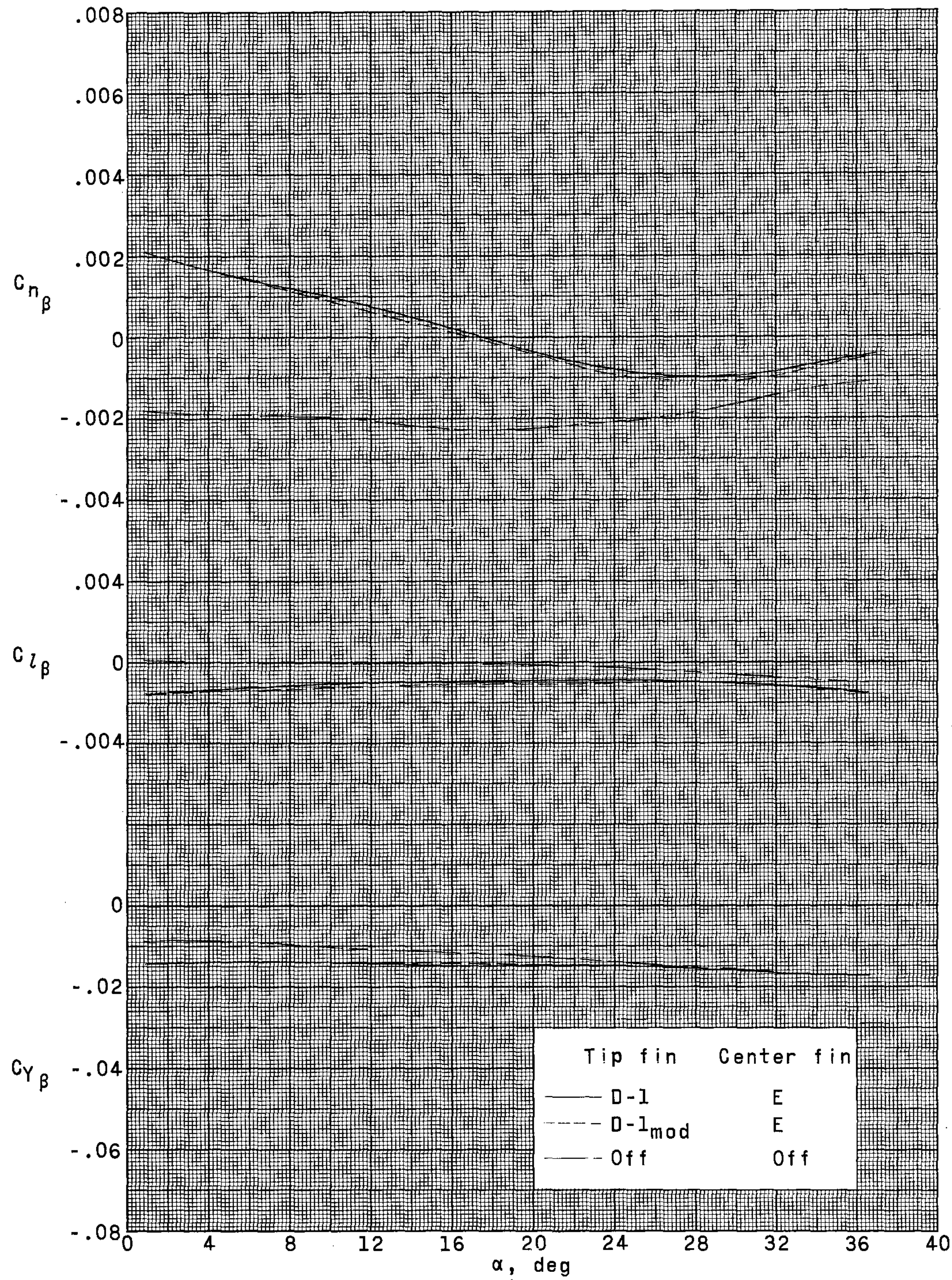


Figure 6.- Summary of longitudinal characteristics of basic model. $\delta_a = \delta_r = 0^{\circ}$.



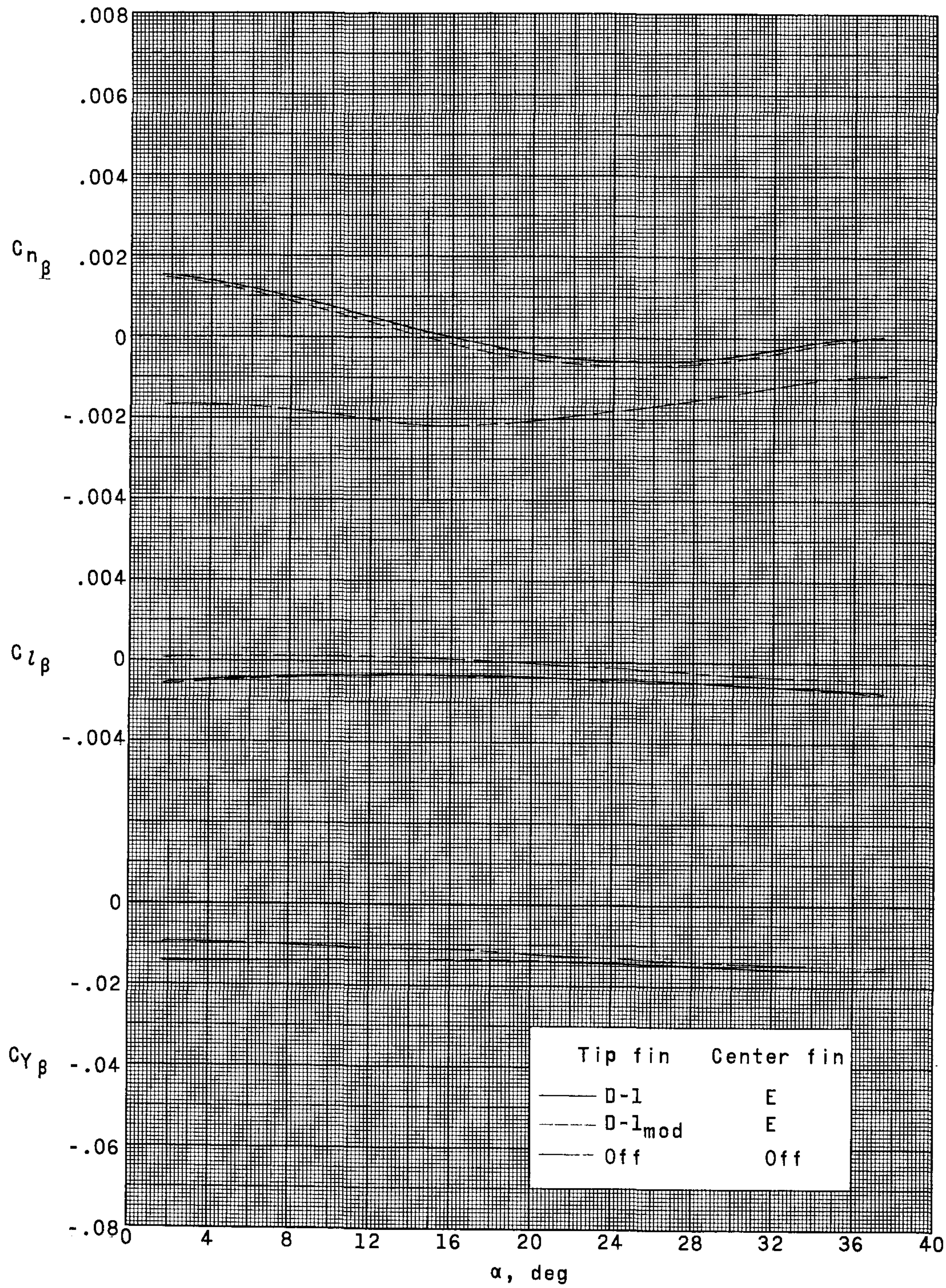
(a) M = 1.50.

Figure 7.- Variation of sideslip parameters of various model configurations with angle of attack. $\delta_e = \delta_a = \delta_r = 0^{\circ}$.



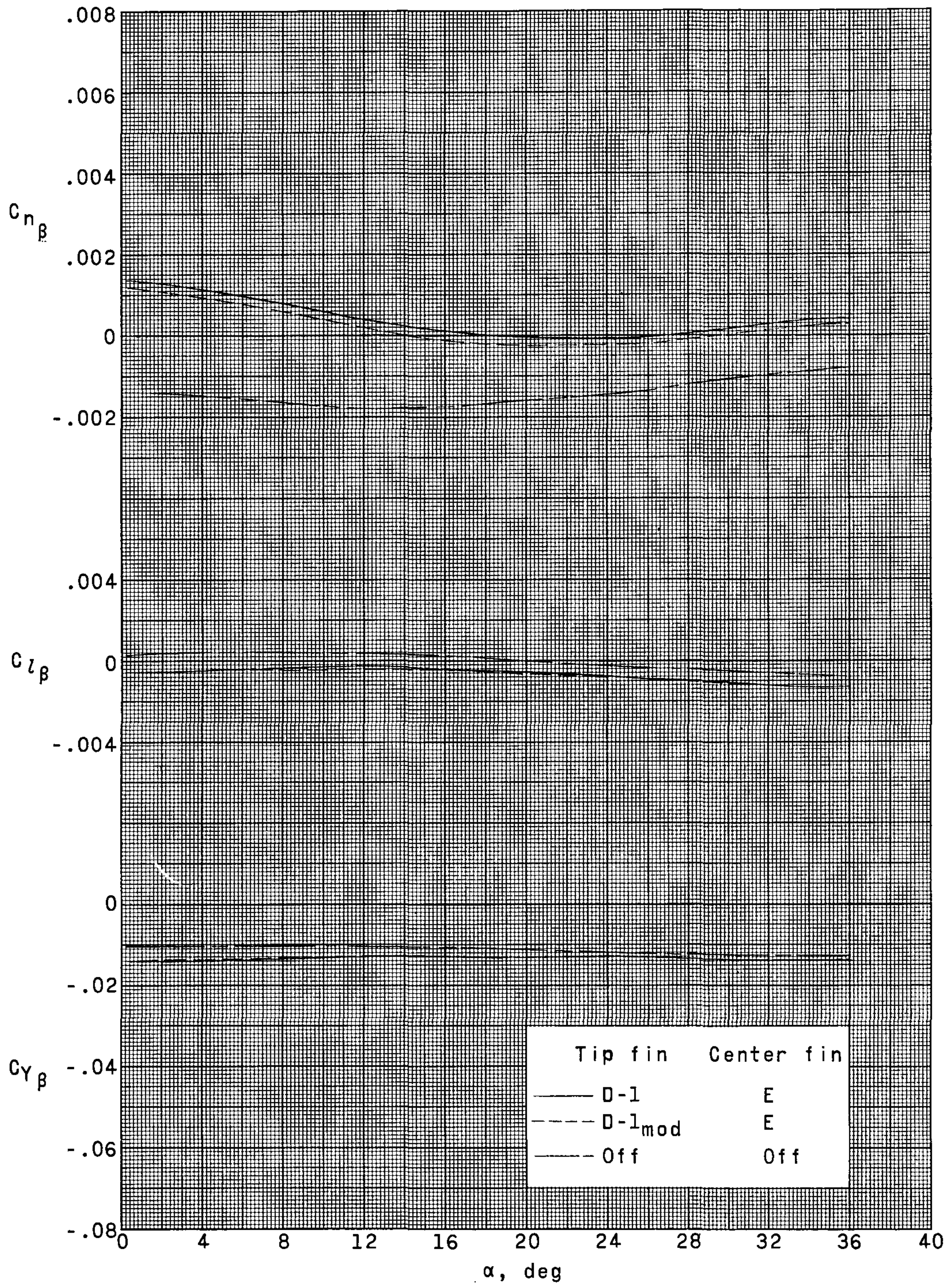
(b) M = 1.80.

Figure 7.- Continued.



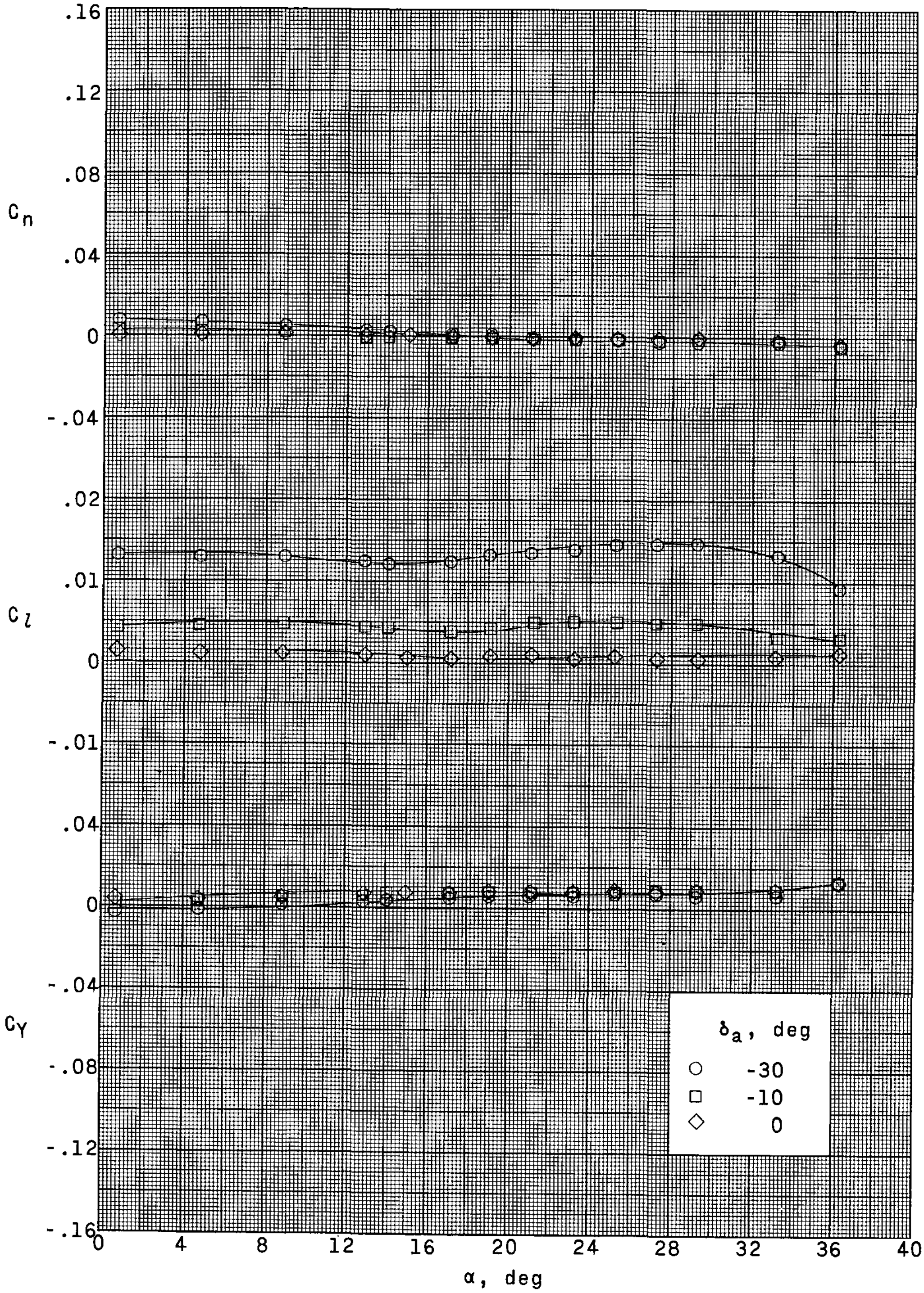
(c) M = 2.16.

Figure 7.- Continued.



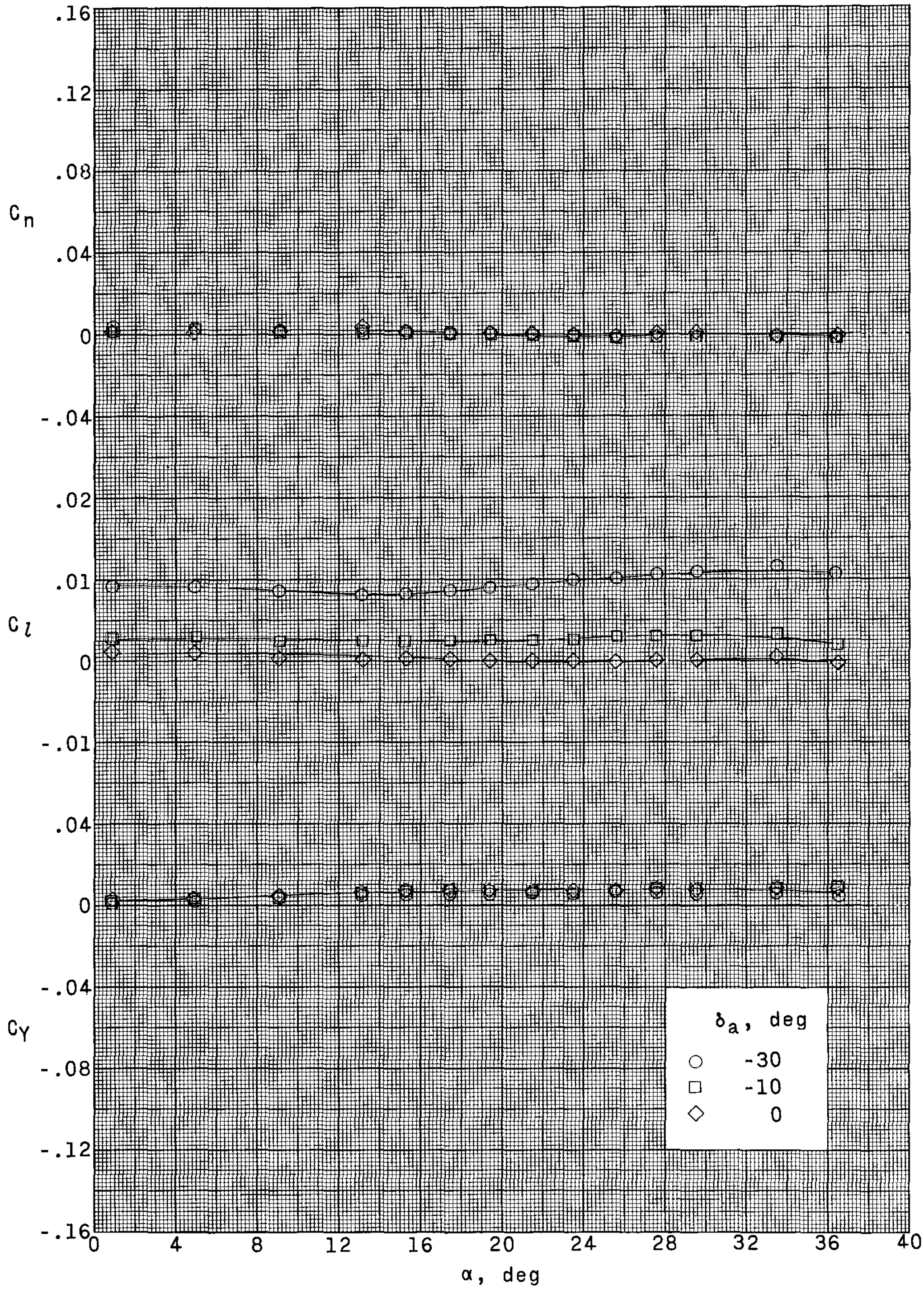
(d) M = 2.86.

Figure 7.- Concluded.



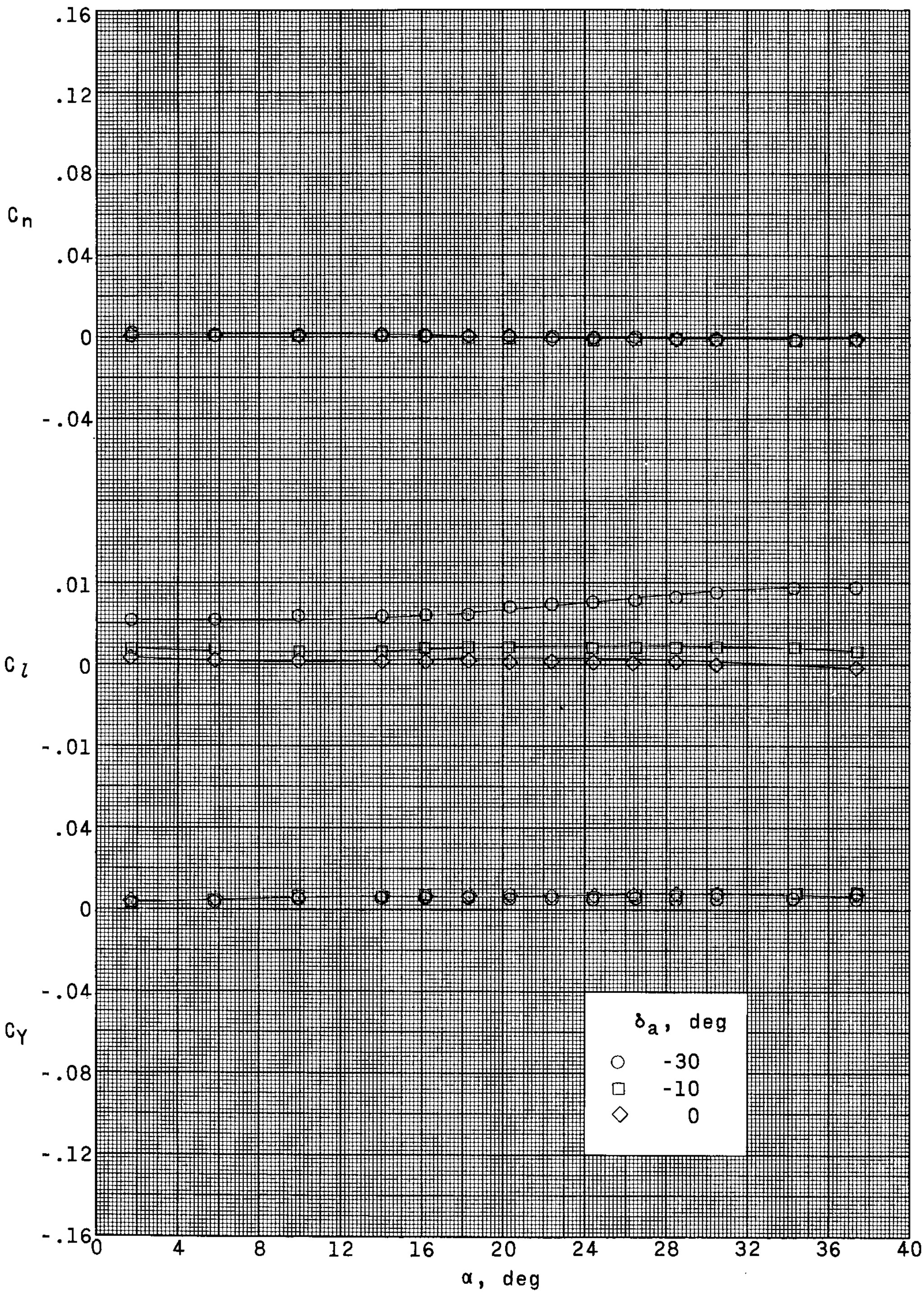
(a) M = 1.50.

Figure 8.- Variation of lateral characteristics of basic model with angle of attack for various roll control deflections. $\delta_e = \delta_r = 0^o$.



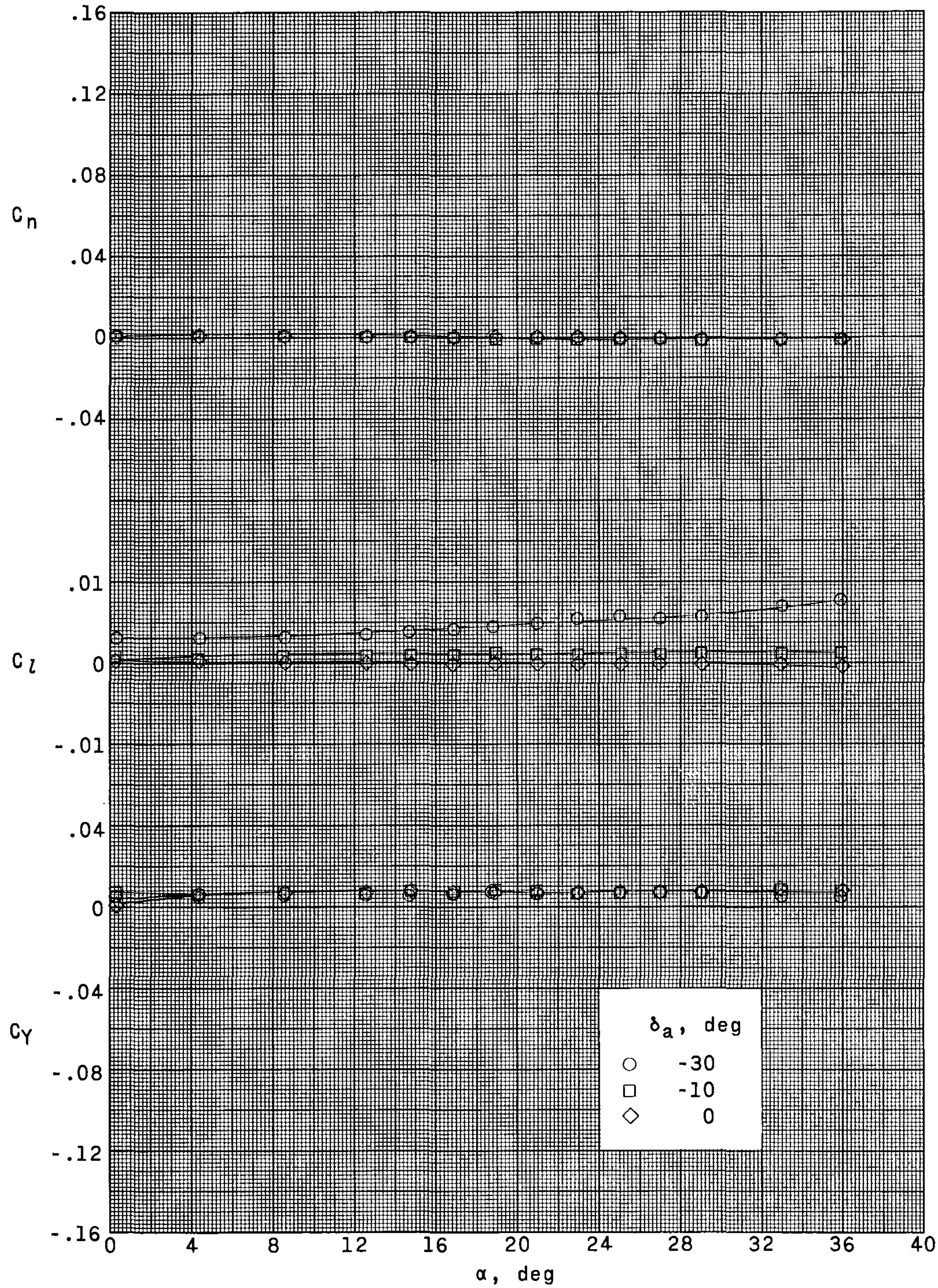
(b) M = 1.80.

Figure 8.- Continued.



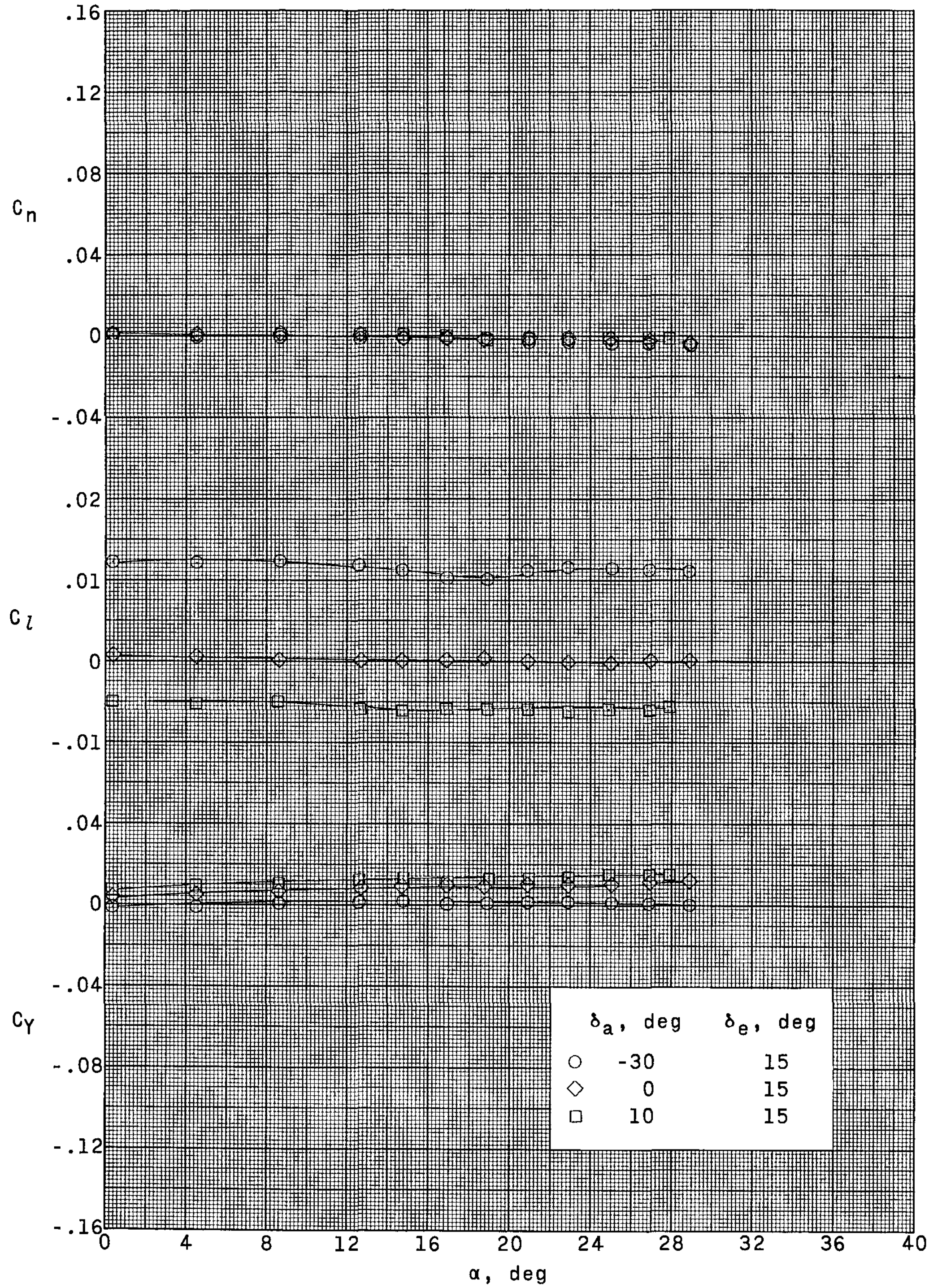
(c) M = 2.16.

Figure 8.- Continued.



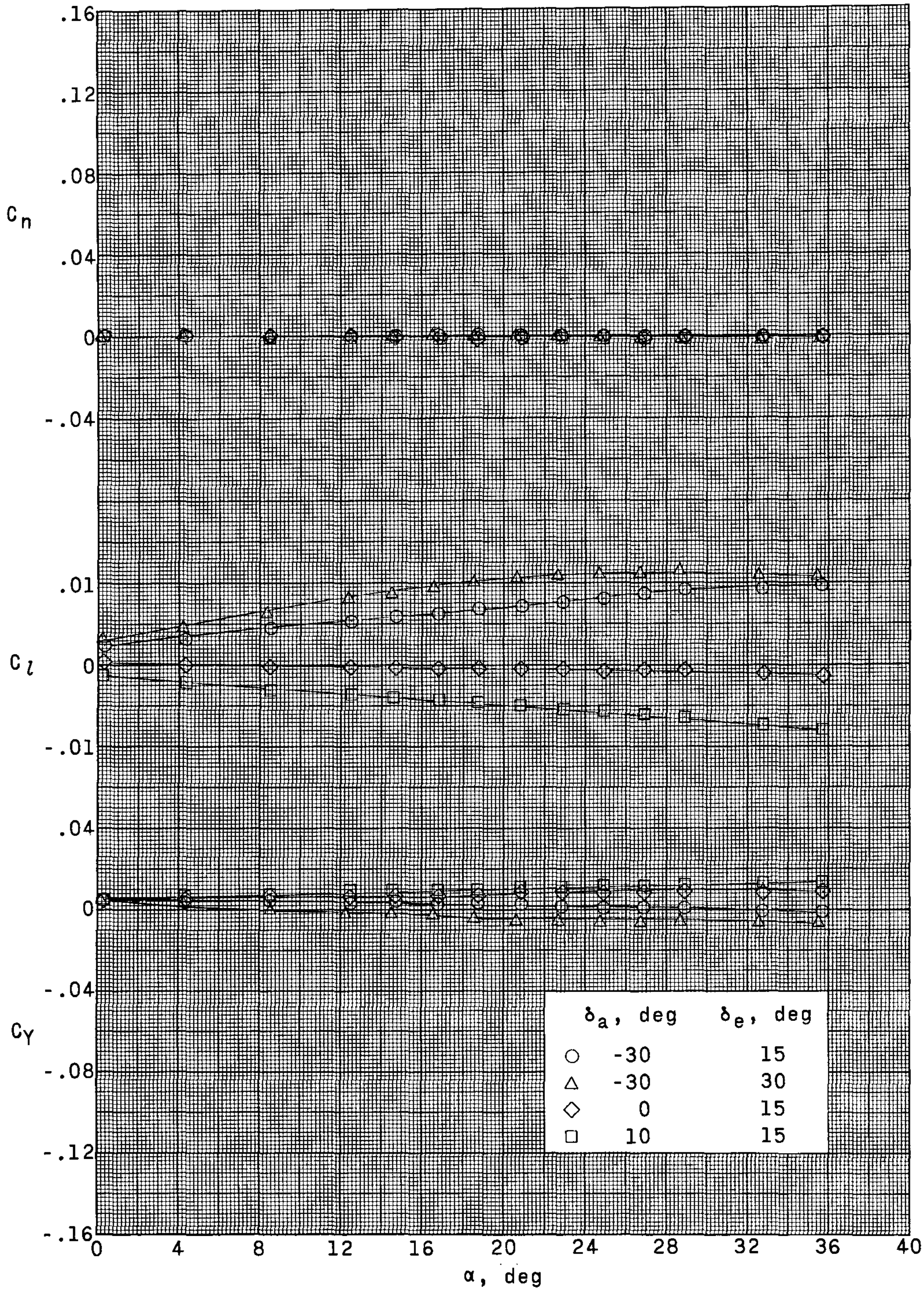
(d) M = 2.86.

Figure 8.- Concluded.



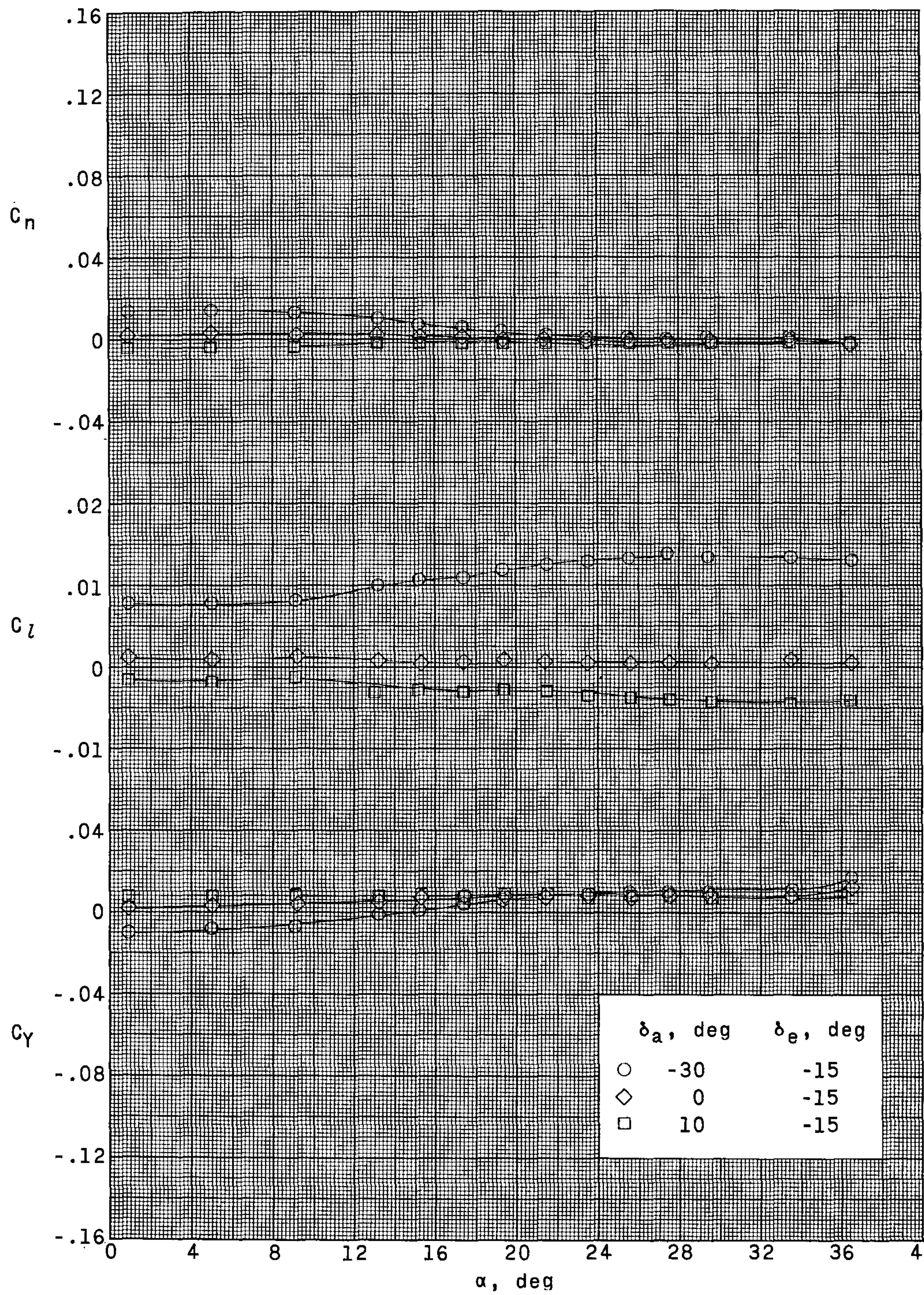
(a) M = 1.50.

Figure 9.- Variation of lateral characteristics of basic model with angle of attack for combined pitch and roll control deflections. $\delta_r = 0^{\circ}$.



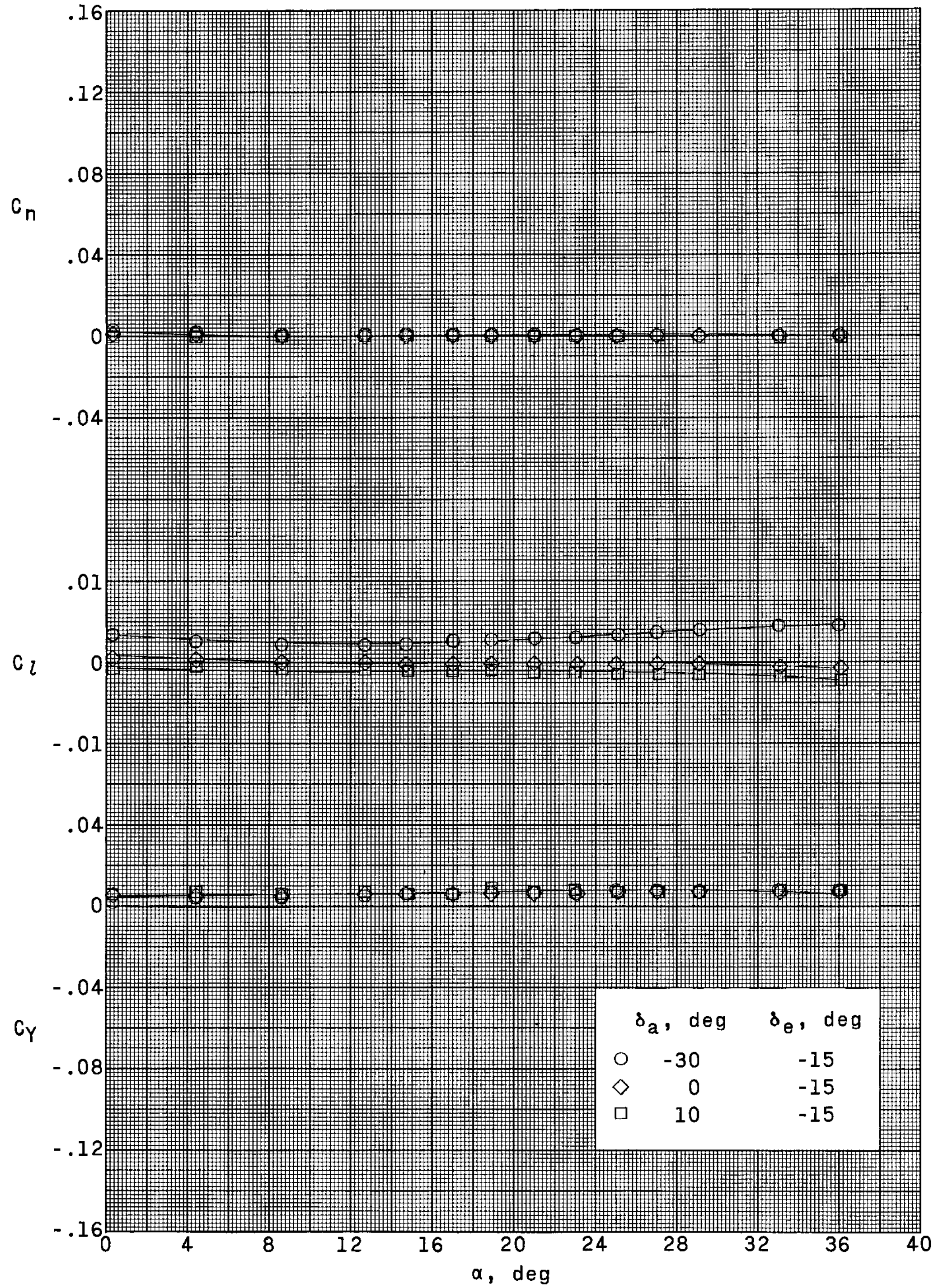
(b) M = 2.86.

Figure 9.- Concluded.



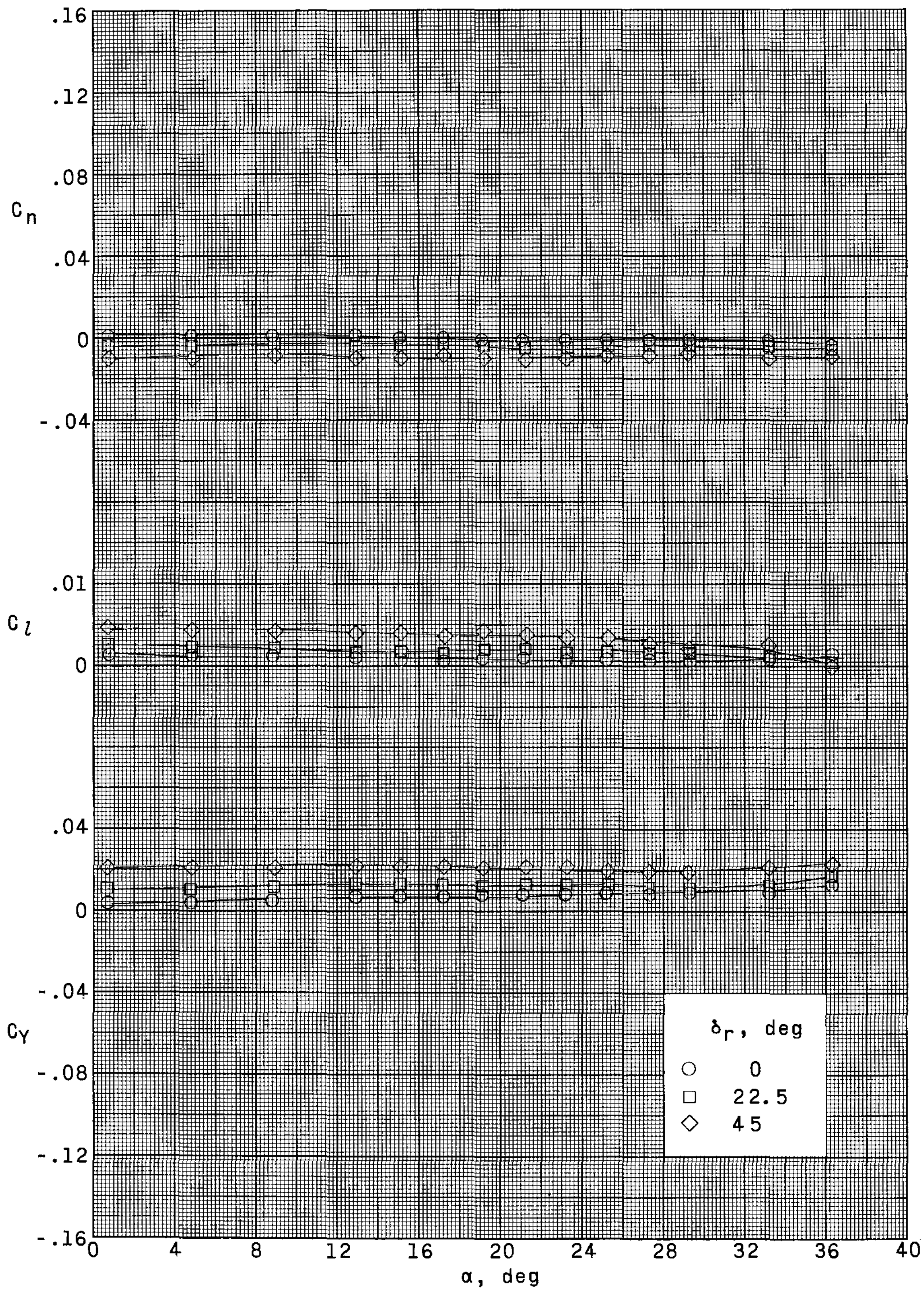
(a) M = 1.50.

Figure 10.- Variation of lateral characteristics of basic model with angle of attack for combined pitch and roll control deflections. $\delta_r = 0^\circ$.



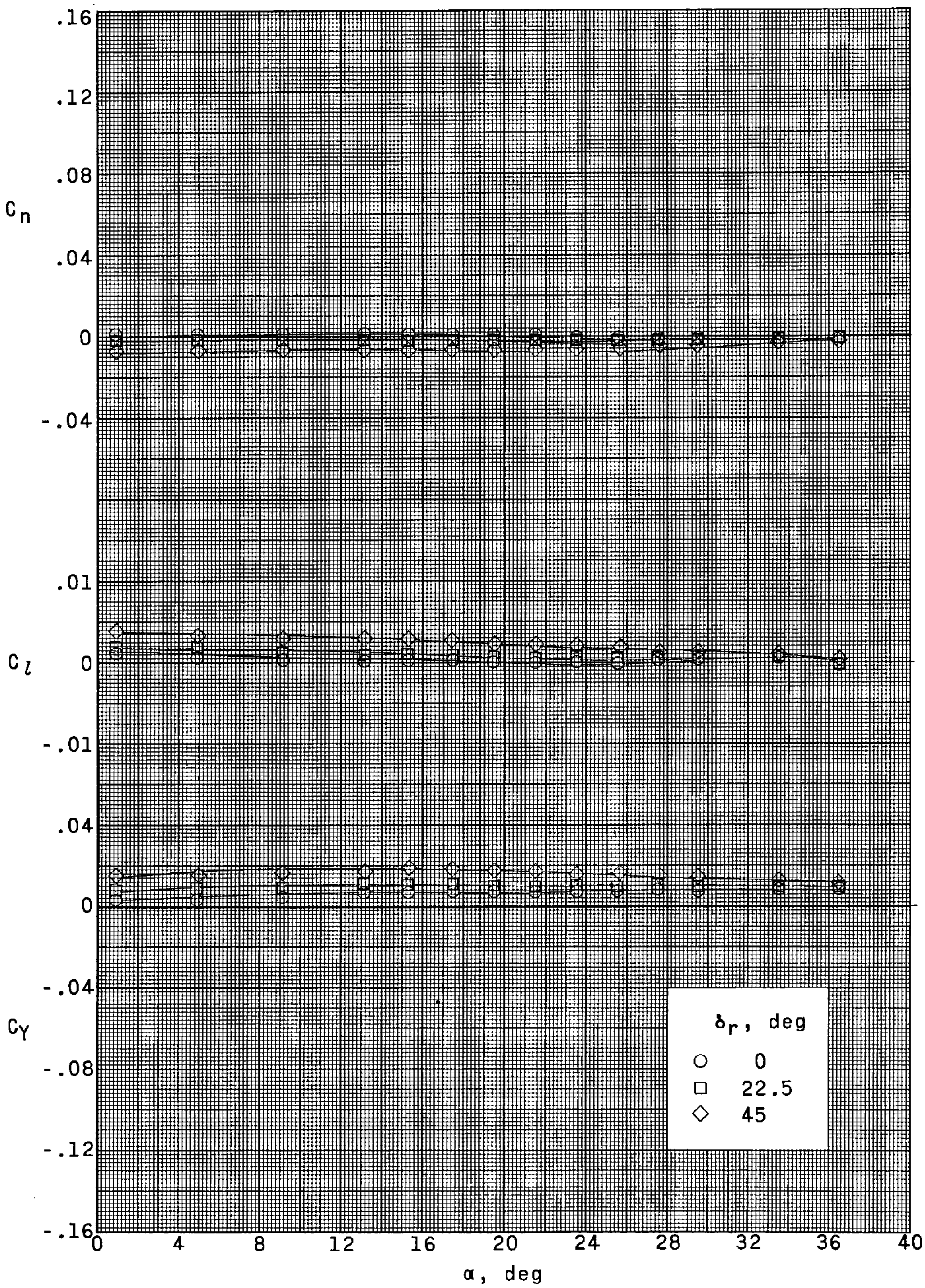
(b) M = 2.86.

Figure 10.- Concluded.



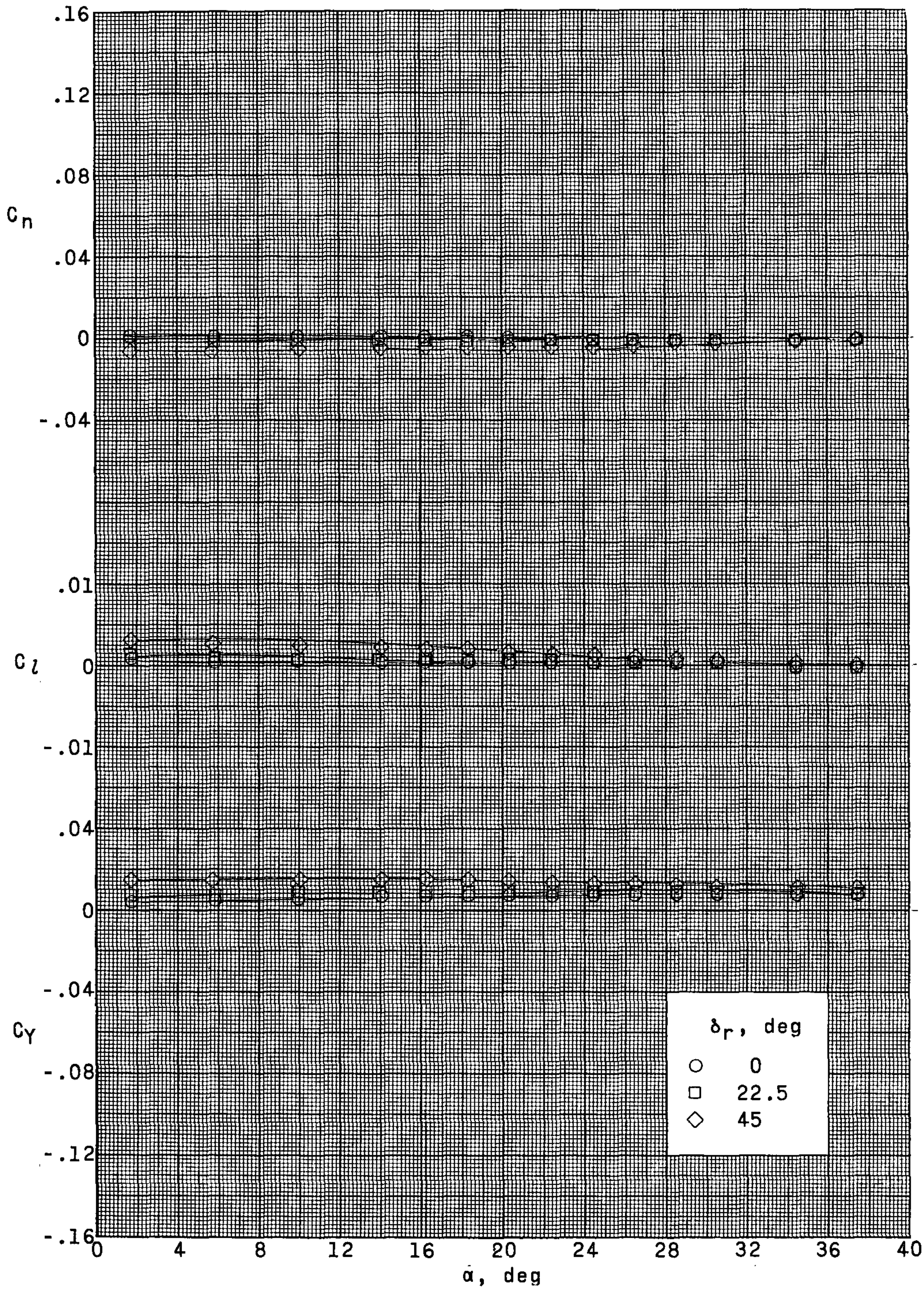
(a) M = 1.50.

Figure 11.- Variation of lateral characteristics of basic model with angle of attack for various yaw control deflections. $\delta_e = \delta_a = 0^o$.



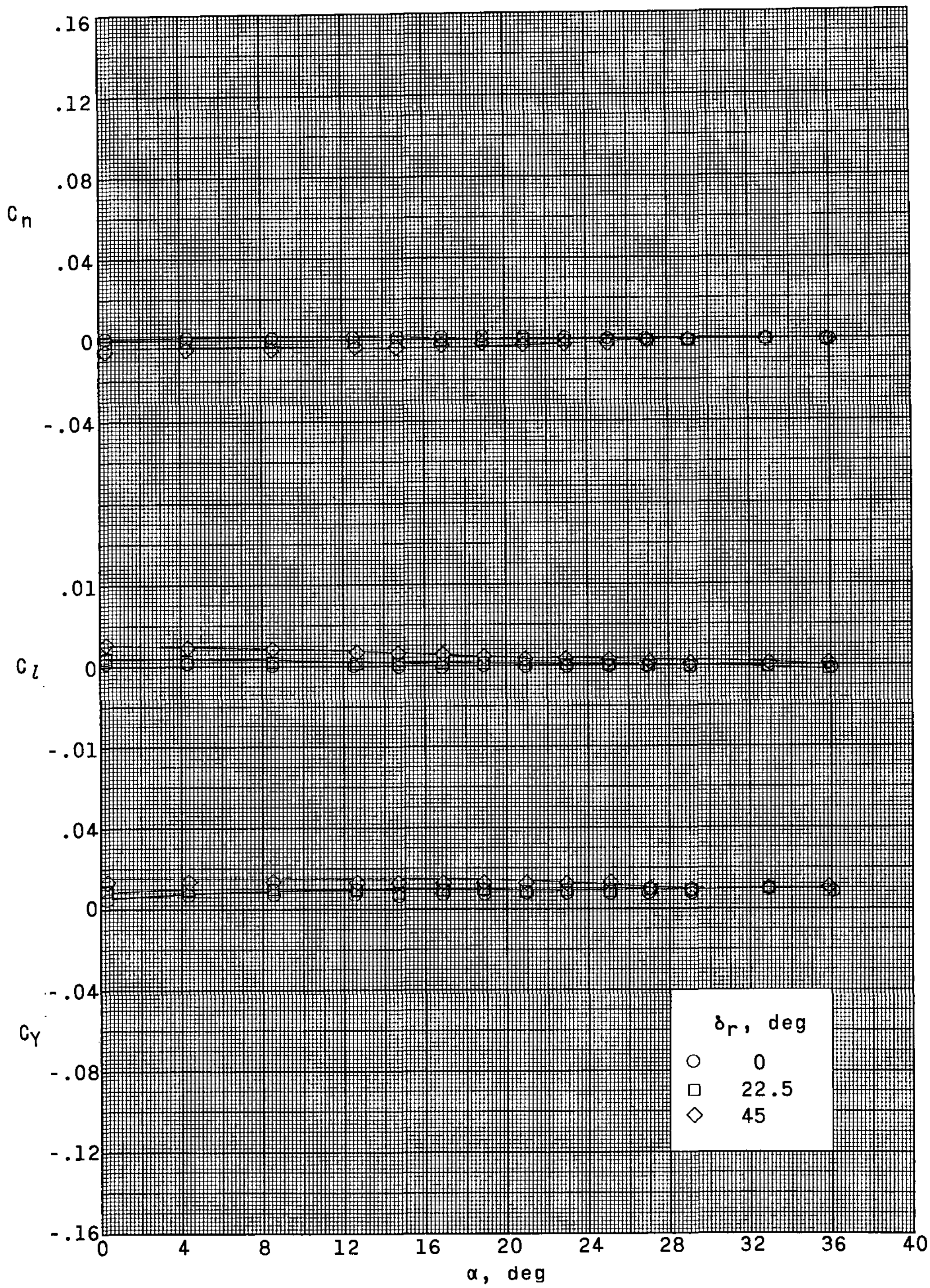
(b) M = 1.80.

Figure 11.- Continued.



(c) M = 2.16.

Figure 11.- Continued.



(d) M = 2.86.

Figure 11.- Concluded.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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